
LANDSCAPE SURVEY IN THE UPPER
AND CENTRAL MACKENZIE VALLEY

STUDIES OF VEGETATION, LANDFORM AND PERMAFROST IN THE MACKENZIE VALLEY:

LANDSCAPE SURVEY IN THE UPPER AND CENTRAL MACKENZIE VALLEY

by

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This is one part of a three-part contribution to the Task Force on Northern Oil Development, by the Northern Forest Research Centre (Canadian Forestry Service, Department of the Environment), Edmonton, Alberta. This contribution is concerned with the mapping of landscape permafrost features using air-photograph interpretation, checked by ground inspection; another with the study of terrain-vegetation permafrost relationships, used to characterize surficial geological map units (S. C. Zoltai); and the third with an investigation of the effects of disturbance in permafrost terrain, and the kind and degree of damage to the terrain caused by different agents (R. M. Strang).

The data for these contributions were obtained by investigations carried out under the Environmental-Social Program, Northern Pipelines, of the Task Force on Northern Oil Development, Government of Canada. While the studies and investigations were initiated to provide information necessary for the assessment of pipeline proposals, the knowledge gained is equally useful in planning and assessing highways and other development projects.

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1 SUMMARY

Using air-photograph interpretation and ground inspection, the landscape of the upper and central reaches of the Mackenzie River Valley has been mapped, using units identifiable in air-photographs to allow extrapolation between the localities of ground inspection. The landscape units delineated on the maps are described in terms of useful surficial and close subsurface characteristics of the permafrost. The distribution of frozen and unfrozen landscape units allowed a rational zoning of climatic changes from south to north and, coupled with a broadly based grouping of units according to the observed damage caused by uncaring traffic (strongly related to texture and slope), a zoning of the landscape by sensitivity to damage from disturbance. The completed maps have been used to correlate with the work of others, where this was available. Incorporating aspects of geomorphology, drainage, pedology and vegetation, they should form the basis for other, similar correlations. The maps also usefully show the distribution of different terrain characteristics for construction work. It is hoped to extend the survey into presently unmapped areas.

2 INTRODUCTION

2.1 Nature and scope of study.

The Canadian Forestry Service was asked to make a vegetation-landform (landscape) input into the survey and mapping of surficial geology throughout a belt of land encompassing the Mackenzie River Valley, a geological survey being carried out by the Quaternary Division of the Geological Survey of Canada. The particular study described in this report was undertaken during 1971 and 1972 in about 17,500 square miles of the upper and central reaches of the Mackenzie Valley, and covered an area where the surficial geology had been mapped discontinuously by N. W. Rutter, O. L. Hughes, P. T. Hanley and R. J. Fulton of the Geological Survey during the years 1970, 1971 and 1972. All the geologists mapped basic units such as lacustrine deposits and morainal till: broad textural differences between one area and another were mapped for most of the region by different people at different times, for example allowing separation of more silty and clayey areas from more sandy and gravelly areas; "peat" and "fens" (to be defined later) had been broadly separated, but slopes had not been consistently delineated throughout the whole region, though they profoundly affect vegetation-landform patterns. Because of the incompatibility of time for co-ordination between landscape surveyor and geological surveyors, it was necessary to, first, produce landscape maps and, second, to correlate these as intimately as possible with the surficial geology maps from area to area.

Additionally, it was found difficult to delineate and describe varied landscape units within the constraints set by another, different classification formulated by the geologists without the loss of much useful information. However, both landscape and surficial geology maps were strongly influenced by the regional geomorphology, and this dependence became the means of correlation. So, using a modified form

of the Biophysical Classification (Lacate, 1969), modified to meet local needs, correlation of landscape maps with surficial geology maps was achieved at the intermediate, Land District (parent material) level. This methodology maximizes the information that can be given for a particular sheet area. The sheets published to date clearly reveal the need in the study area for two separate classification structures and resulting maps. In some places the surficial geology needs much more careful delineation than the landscape units, whereas in other places there is a much greater local variation in the landscape patterns, a variation which needs delineation on maps to be of maximum use to the engineer. The landscape survey places greater emphasis on the near-surface conditions, whereas the geological survey emphasizes conditions at greater depths; the one is intended to be complementary to the other.

2.2 Specific objectives

The primary objectives of this study are to determine the relationships between vegetation, landform and permafrost which are of value to the engineer: to present the information in map form at suitable scales so that the information is readily accessible to the engineer; to define the landscape units, or composite patterns of vegetation and landform (chiefly drainage microrelief), in terms that can be anticipated in standard black and white air photographs so that, if necessary, the information can be extrapolated outside the particular area of study and so increase the value of the survey (though such extrapolation will extend outside the detailed coverage of surficial geological mapping), and to rate the landscape units meaningfully by sensitivity to disturbance from uncaring traffic on this kind of terrain. Finally, using the maps so produced, to correlate with as many as possible of the other Departmental Branches working within the framework of the Mackenzie River Valley studies.

2.3 Relationships to concerns about pipeline development

The engineer must know of terrain where construction problems will be similar to those further south, and where nearness to the land surface of the permafrost may present problems not experienced elsewhere. In particular, certain areas characterized by an intricate patterning of frozen and unfrozen ground near the surface; an environment completely alien to most engineers and where the normal straight line, cut and fill levelling operation will require fundamental changes in tactics from point to point if uneconomic maintenance costs are to be avoided; if the delicate ecological balance associated with this area is not to be harmfully disturbed, and if the natural wild beauty of the landscape is to be

Fig. 1. Location of the study-area, showing physiographic regions, mean annual air temperature (°F) (Brown, 1967), mean annual precipitation (inches) (Burns; pers. comm.), and some aspects of the topography.

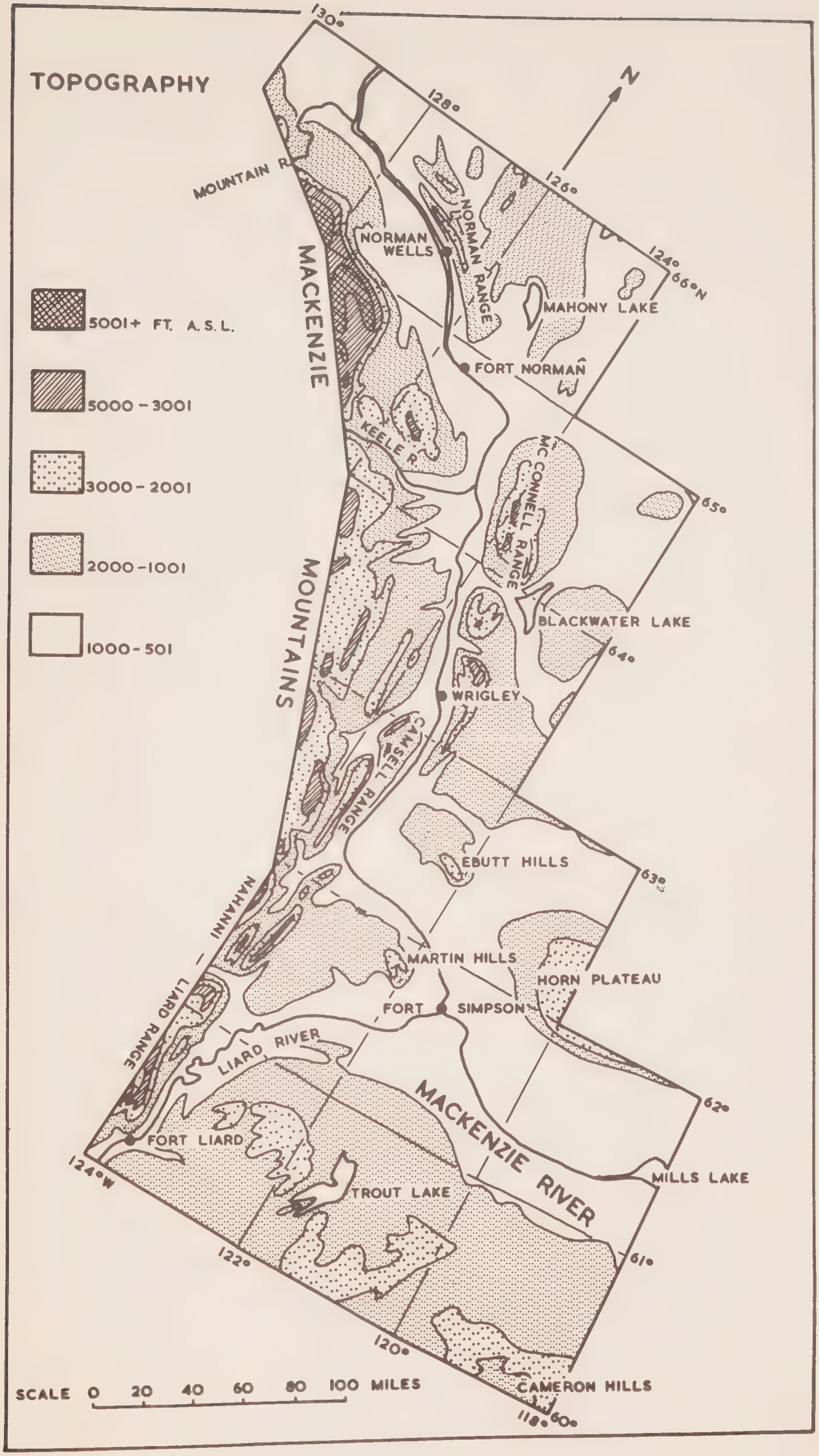

Fig. 2. Topography of the study area.

preserved for the future. Such areas highly sensitive to disturbance are best avoided, but if they cannot be avoided (and in certain areas where, for example, because of mountains pressing in on either side of the Mackenzie River, they cannot be avoided), then the engineer must know of the special considerations associated with each parcel of land.

3. CURRENT STATE OF KNOWLEDGE

Existing knowledge of the North is piecemeal and related to widely scattered localities, each with its peculiar problems. The study-area incorporates both land which presents no new problems to the engineer from the south, and also land which is as susceptible to damage from unconcerned traffic as the Arctic barrens. Hence, there is the primary need for a systematic coverage of the Mackenzie Valley, even if for economic reasons it is in the form of a reconnaissance survey. Most maps are generalizations; they delineate areas consisting mostly (say, 80% of each area) of one kind of terrain. Despite this unavoidable deficiency, maps are the best means of conveying certain kinds of terrain information to the user. The effects of the deficiency can be mostly offset by supporting each map with an adequate legend and terrain descriptions, so that the user can reasonably detect when the map information is no longer relevant to the land under his feet, and so that he can adjust his actions accordingly.

4 STUDY AREA

4.1 Climate

The area of interest for this report includes the southern and central Mackenzie River Valley, from the Northwest Territories-Alberta border (latitude 60° N), with the Cordilleran Region (Mackenzie Mountains) on the west side and Great Slave and Great Bear Lakes separating the Canadian Shield on the east side, northwards to the southern fringe of the Arctic Lowlands (66° N) (Fig. 1). The study-area lies within the Discontinuous Permafrost Zone, although mountain ranges and plateaus, especially where they constrict major valleys, become "outliers" of the Continuous Permafrost Zone, at the highest altitudes producing Alpine tundra which is equivalent to the true Arctic Tundra. However, isotherms are generally aligned northwest-southeast (Fig. 1). Isohyets indicate a mean annual precipitation below 15 inches throughout the Mackenzie Valley in the study-area, though the precipitation over adjoining highlands to the east and west of the river such as the Norman and McConnell Ranges, the Horn Plateau and the Cameron Hills (Fig. 2) exceeds this value. Over the Cameron Hills, and the Mackenzie Mountains where they impinge on the west of the study-area, the mean annual precipitation exceeds 20 inches (Fig. 1).

4.2 Physiography

Devonian shales and limestones crop out over a large part of the Mackenzie River lowlands (Fig. 3) where the surficial deposits are thin, giving rise to near-neutral soils. Plateau-lands, for example, Horn Plateau and the Cameron Hills, south and east of the Mackenzie River are formed of Lower Cretaceous shales and sandstones, capped by Upper Cretaceous sandstones and shales. The prominent Norman, McConnell and Nahanni Ranges are formed by thrust masses of Silurian-Ordovician dolomites, limestones and shales. Devonian limestones and shales help form the Mackenzie Mountains, as locally do the Carboniferous-Permian sandstones and conglomerates and Cambrian-Precambrian sandstones, dolomites and shales. In the central study-area, poorly consolidated Tertiary sandstones and conglomerates crop out on either side of the Mackenzie River between dissected terraces near the river, and boulder-covered mountains further west.

During the Pleistocene, ice from the Canadian Shield moved west, impinging and penetrating the Mackenzie Mountains in the study-area and in retreat, depositing a varying thickness of till, thin especially on ridges and slopes. During ice retreat, two major glacial lakes were impounded, one along the Mackenzie and Liard River Valleys in the south of the study-area (Craig, 1965), and one along the Mackenzie River Valley in the north of the study-area, laying lacustrine deposits across these areas, usually not very thick. Locally these deposits were subsequently resorted by wind, forming dunes.

5 METHODS AND SOURCES OF DATA

5.1 Map production

After air-photograph interpretation of different vegetation-landform patterns, the significance in terms of permafrost of each of the delineated patterns was determined by ground inspection. Initially, both tasks were done concurrently in the field, so that there was interaction between possible pattern differentiation from air-photographs and the usefulness of these patterns for separating areas with different permafrost relationships. Once the limits of the methodology had been determined, air-photograph interpretation was done during winter in the laboratory and then checked by ground inspection during summer. In this manner as complete as possible a knowledge of each of the delineated landscape patterns was accumulated. At the end of the two summer field seasons small gaps in the air-photograph coverage were filled by extrapolation using whatever means were available, and the boundaries between map-sheets or mosaics checked for consistency of interpretation. The maps were then reduced, first to a scale of 1:250,000 so that all available information could be presented as reasonably accurately as possible on standard topographic maps, and second, to a scale of 1:600,000 so that the total area could be shown on one map for an overall appreciation of the distribution of landscape units.

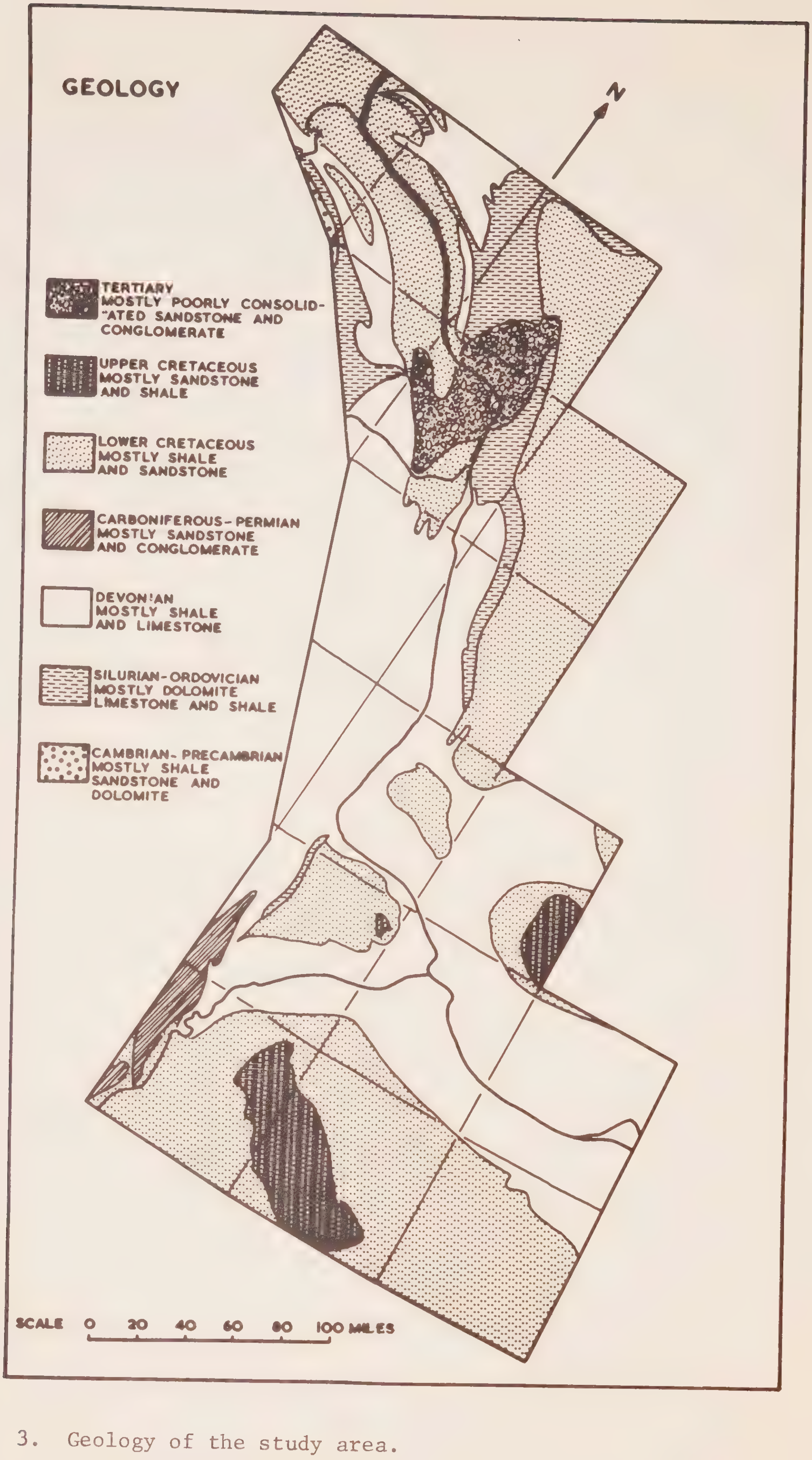

Fig. 3. Geology of the study area.

The first digit of each full unit symbol on the maps gives the Land Region or climatic zone; the second digit the Land District or surface geology, and these are shown in large numerals. A hyphen separates this information from the third, small numeral indicating the Land System or landscape unit; in most cases this information is shown separately on the map. All major areas have been identified in terms of the dominant landscape unit number. As an example, the complete symbol 31-12 means the (relatively cool) Horn Plateau Land Region, silty-clayey morainal till and coarsely lineated gentle slopes with near-surface permafrost, though in most places only the 12 would be printed. The landscape units have been assigned to four groups for susceptibility to damage from uncaring traffic. A broad regional appraisal can be made by viewing only the distribution of these four groups, shown by shading or by the assignment of the letters A-D. A more detailed assessment can be made by examining the distribution of individual landscape units, and for this purpose a brief description of each unit is given in the table below the legend. The legend gives the general tree height and typical ground vegetation associated with the different land systems. Without further restatement, constant reference to these maps is intended throughout the report. If detail is not required any of the maps can be used independently of the report. For accurate assessments of the terrain at any one place, reference to the report is essential.

5.2 Land Regions

The survey involved the fields of geomorphology, pedology and biology, and so the classification of landscape units was structured on a modified form of the Biophysical Classification. The highest level of this classification, the Land Region, is intended to be equivalent to a climatic zone, and so a means was sought for zoning the study area by climate. During the course of the survey it was apparent that there was a natural grouping of landscape units within discrete areas, each area characterized by particular proportions of frozen and unfrozen land. The vegetation, for example the tree species distribution, failed to identify these areas because of the ubiquitous nature of many trees, except for differentiating the extremes. It also became apparent that the soil associated with a particular site type ranging throughout the study-area, (the freer-drained site associated with many terraces, river and terrace banks, morainal and glacio-fluvial ridges), best characterized climatic zoning and related usefully to the proportions of frozen and unfrozen land in the total landscape. Using the actual distribution of landscape units and a knowledge of the distribution of soils on the selected site type, climatic zonal lines were drawn on the maps, giving Land Regions (Fig. 4).

The most southerly "Trout Lake" Land Region 6 is characterized by "podzolized" dystric brunisols on freer-drained sites, the most podzolized soils in the study area. The climate of this Region is conducive to pedogenesis in the form of a biochemical redistribution of certain elements to give a horizontal layering in the soil profiles. In the next "Fort Simpson" Land Region 5 to the north of 6, podzolization in soils on the freer-drained sites is not so pronounced, and the soils may be described as degraded dystric brunisols. This trend continues northwards, with degraded eutric brunisols in the "Norman Wells" Land Region 4 and alpine

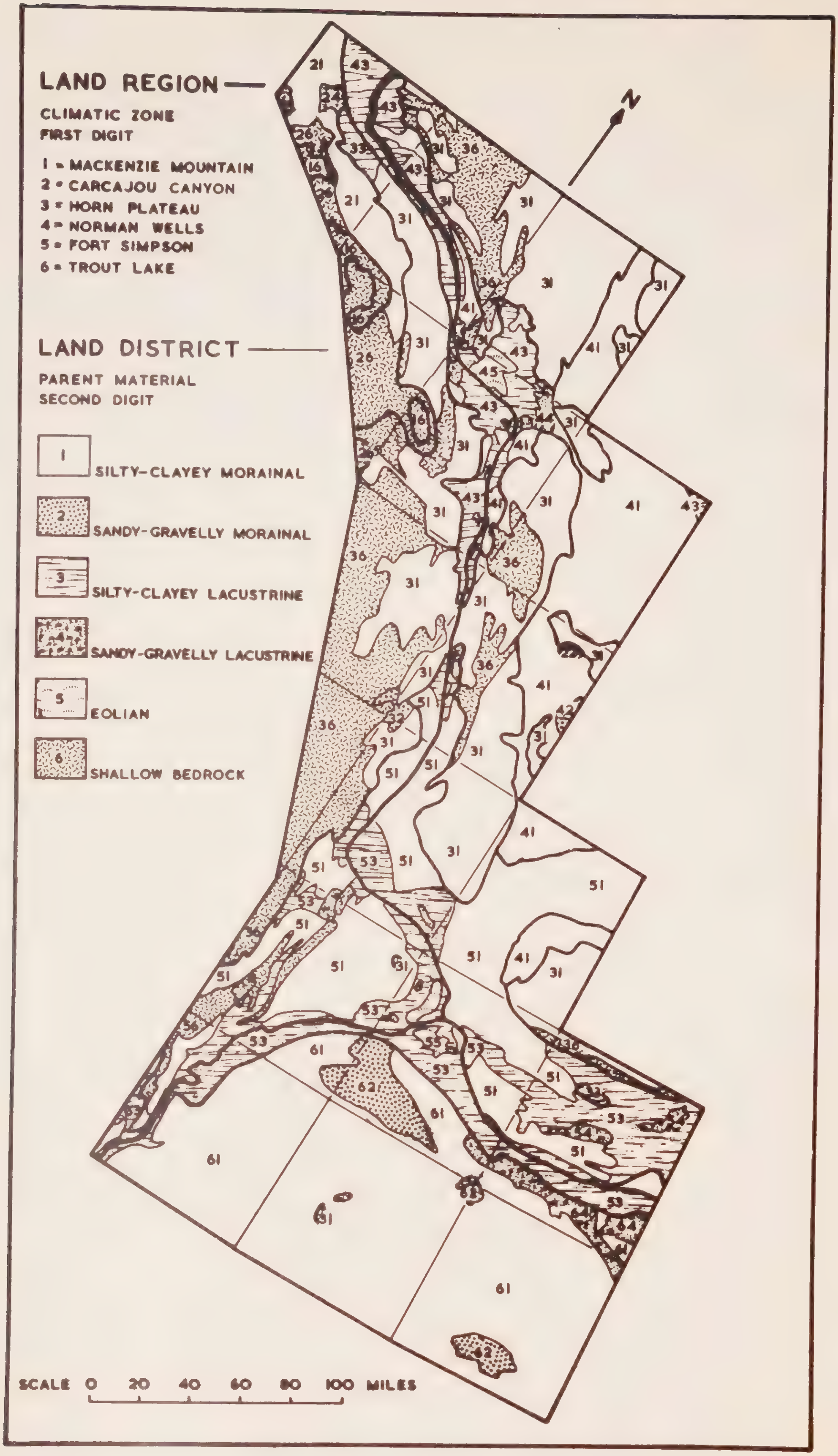

Fig. 4. Distribution of Land Regions and Land Districts.

eutric brunisols in the "Horn Plateau" Land Region 3. Further north or at higher elevations podzolization is no longer apparent in the soils, which are then termed regosols indicating a minimum of bio-chemical activity. In the "Carcajou Canyon" Land Region 2 the cryic regosols on freer-drained sites, especially alluvial terrace sites, are shallow over the permafrost table. Within so-called "turbic" regosols occurring on freer-drained sites in the alpine tundra of the "Mackenzie Mountain" Land Region 1, actively heaving soils are evidenced by disruption of the vegetative mat, and sometimes concentric sorting of fragment sizes (e.g. sorted circles, Washburn, 1956, over Tertiary conglomerates). The profile layering suggests a movement of organic material down cracks wedged open by seasonal freezing, down the summer surface of the permafrost which, in this case, slopes gently away from the cracks and, with the mineral soil, upwards towards a central orifice, giving in the soil profile a vertical component. The trend from podzolized soils (indicative of a warmer climate), to cryoturbated soils (indicative of a cooler climate), is illustrated by selected soil profiles (Fig. 5).

5.3 Land Districts

Land Districts have been interpreted as representing the basic parent materials in the surficial geology, insofar as common units could be extracted from the several source maps produced by the Geological Survey. Correlation with the Geological Survey was achieved at this level of classification. The many units of the Geological Survey have been simplified to six, separating morainal from lacustrine deposits and silty-clayey from sandy-gravelly textures (Land Districts 1, 2, 3 and 4 in Fig. 4), areas with sand dunes (Land District 5) and areas with shallow bedrock (Land District 6). These surficial materials have an important influence on the distribution of permafrost, though greater elaboration of this subject is best undertaken in the geologist's reports.

5.4 Land Systems

Land Systems are landscape units of vegetation-landform patterns, identifiable on air-photographs, which have significance in terms of presence or absence of permafrost and of thickness of the active layer (depth to the late-summer permafrost table). The kind of landform used is usually the local relief arising from surficial drainage distribution, superimposed upon the macrorelief arising from the underlying geomorphic structure. The kinds of vegetation which are generally associated with the landform tc produce a characteristic pattern identifiable in air-photographs includes forested land, land with rich sphagnum cover, or a rich lichen cover, or various combinations of two or three of these elements.

Continuously forested lands are most freely drained, sometimes imperfectly drained; lands with much *Sphagnum* spp. (and sedges) are surficially waterlogged in the summer (hence-forward, "seasonally

waterlogged lands"); lands with much lichen in the vegetative cover are usually dry at the surface. Such dryness can arise because the substrate is excessively drained (as in podzolized soils on sandy-gravelly soils in the south) or, elsewhere in the study-area, where the summer permafrost table is close to a surficially dry land surface. In some areas this surficial dryness gives the summer landscape a desiccated appearance, despite the nearness of "high-ice" permafrost. (In "high-ice" permafrost, water must always be present in the frozen substrate as ice in order to maintain its natural mechanical properties.) A dry surface to peat helps insulate the underlying permafrost (Brown and Johnston, 1964). This dryness, with a thick ericaceous and birch shrub layer that so frequently accompanies lichen on these sites serves as fuel for irregularly distributed intense fires that burn deeply (Cochrane and Rowe, 1969). After such intense fires the permafrost table lowers and there are great changes in the appearance of the landscape. Interpretive mapping takes account of this by comparison with unburnt areas.

5.5 External sources of data.

Land Regions and Land Systems are based on data collected by the author. Land Districts are based on data from the Geological Survey of Canada. Grouped Land Systems were correlated with current vegetation units defined by W. L. Wallace during a survey by the Forest Management Institute. Grouped Land Systems were also correlated with more detailed observations collected by R. M. Strang (of the Edmonton Laboratory, Canadian Forestry Service) from selected localities in the study area. A correlation was attempted with certain aspects of the Canadian Wildlife Service's contribution to the Task Force on Northern Oil Development.

6 RESULTS

Mineral soils and rock outcrops (Fig. 6)

6.1.1 *Land System 1:* mountain rock outcrops and screes (Figs. 10 and 22)*.

Bare rock outcrops with screes on steep slopes occupy most of this particular landscape in mountainous areas. Dwarf black spruce (*Picea mariana* (Mill.) BSP) has a foothold in regosols on some of the more stable screes. The thin ground flora is often ericaceous shrubs, with lichen. On high-altitude mountain plateaus there is a characteristic alpine flora.

6.1.2 *Land System 2:* freer-drained mineral soils without near-surface permafrost (Figs. 10, 11 and 15).

This unit occurs on freer-drained sites; specifically, freely-drained dystric (south), eutric (central and east) and alpine (north and west) brunisols or, if no freely-drained soils occur in an area as often in the north, imperfectly drained, gleyed dystric and eutric brunisols, all soils with a pH about 3-5. Such sites are associated with many terraces, river and terrace banks, morainal and glacio-fluvial ridges; these sites were used to characterize the climatic zoning, previously equated with Land Regions. Typically, these sites are forested with the most useful merchantable stands in any area. The most widespread species

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* For convenience, the stereograms are grouped together at the end of this report, before appendices.

GROUP	LAND SYSTEM NO.	GENERAL CHARACTER	% IN LAND REGIONS 1	2	3	4	5	6	% IN TOTAL STUDY AREA
Linear-patterned slopes	14	Hilly moraine and finely lineated slopes with near-surface permafrost.		4	1				1
	13	Rocky plateaus, and finely lineated slopes with near-surface permafrost.	26	22	22	1			8
	12	Gentle, finely lineated slopes with near-surface permafrost.		10	8				3
	11	Moderate, finely lineated slopes with near-surface permafrost.		4	12	4	1		4
	6	Steep, lineated slopes without near-surface permafrost.			5	5	5	9	6
Terrazoid-patterned peaty lands	10	Hummocky peat plateaus with lichen and near-surface permafrost, and scattered depressions containing summer pools.		14	6	2			3
	9	Hummocky, peaty mineral soils with near-surface permafrost.		18	15	13			7
	8	Peat plateaus with labrador tea, locally with near-surface permafrost, and scattered depressions containing summer pools.			2	14	20	22	13
Seasonally water-logged lands	5	Drumlinoid terrain and inter-vening seasonally waterlogged lands, locally with near-surface permafrost.		1	3	2	1	1	2
	4	Waterlogged lands with near-surface permafrost.		1	5	53			10
	3	Waterlogged lands without near-surface permafrost.					54	56	27
Mineral soils and rock out-crops	7	Freer-drained mineral soils with near-surface permafrost.	9	12					1
	2	Freer-drained mineral soils without near-surface perma-frost.			3	6	12	12	8
	1	Mountain rock outcrops and screes.	65	14	18	1	6	1	8

Fig. 6. Grouped Land Systems and % of each Land System in each Land Region and in total study area.

is white spruce (*Picea glauca* (Moench) Voss), though black spruce and jack pine (*Pinus divaricata* (Ait.) Dumont = *P. banksiana* Lamb) often occur on the least fertile and most podzolized sites, notably in the south of the study-area where podzolized soils are common. The jack pine stands are usually associated with a rich, lichen (mostly *Cladonia alpestris* (L.) Rabenh.) ground flora with schreber moss (*Pleurozium schreberi* (BSG.) Mitt.) on sandy-gravelly soils; an exceptional association in this study area since abundant cladonia is generally associated with near-surface permafrost. In the north of the study, white birch (*Betula papyrifera* Marsh.) normally accompanies white spruce.

The ground flora in Land System 2 is normally richly herbaceous, including species such as bunchberry (*Cornus canadensis* L.) maianthemum (*Maianthemum canadense* Desf.) and fireweed (*Epilobium angustifolium* L.), with shrubs such as the wild rose (*Rosa acicularis* Lindl.), dogwood (*Cornus stolonifera* Michx.) and dwarf raspberry (*Rubus pubescens* Raf.), and often grassy with species such as *Calamagrostis canadensis* (Michx.) Nutt. Shiny moss (*Hylocomium splendens* (Hedw.) BSG) is widespread on freely drained sites, with some plume moss (*Hypnum crita-castrensis* Hedw.) on imperfectly drained sites. After fire, trembling aspen (*Populus tremuloides* Michx.) grows on freely drained sites, and balsam poplar (*Populus balsamifera* L.) on imperfectly drained sites, eventually accompanied by an understory of white spruce, except where there is jack pine. Fire has been a sufficiently frequent ecological factor that, outside of mountainous areas, few stands on these sites exceed 100 years of age. Within protected areas such as mountain valleys or on ridges surrounded by extensive waterlogged land, some stands exceed 200 years of age and a 100 ft in height. These stands are probably too local to be of long term economic value. However, they could be a local source of pilings.

Frozen ground, usually occurring at about 6 ft depth, is not extensive and occurs mostly in silty-clayey lacustrine deposits.

6.1.3 *Land System 7*: freer-drained mineral soils with near-surface permafrost (Figs. 16 and 20).

Biochemical activity is sufficiently reduced in the Carcajou Canyon and Mackenzie Mountain Land Regions 2 and 1, in the northeast of the study area or at high altitude, respectively, that pedogenesis is insignificant and the profiles are regosols without normal soil horizonation. Sedimentary layering in terraces is well preserved because of the absence of pedogenesis. A near-surface summer permafrost table in cryic regosols associated with many freer-drained sites in the Carcajou Canyon Land Region 2 encourages a rich growth of lichen at the land surface, which can be seen as white in air-photographs, between white (and black) spruce trees that are more widely spaced than in Land Regions 3 to 6. In the high altitude alpine landscape of the Mackenzie Mountain Land Region 1, the soil profile is disturbed vertically by frost heaving, giving "turbic"

regosols. There is a greater variety of lichens, some of which are dark in colour, in the ground flora of this land system. Consequently, there is not the high albedo normally associated with light-coloured lichenous land where the lichens help insulate the permafrost. At these higher altitudes, tree height is restricted to within about 1 ft of the ground.

Seasonally waterlogged lands

6.1.4 *Land System 3:* seasonally waterlogged lands without near-surface permafrost (Figs. 11 and 17).

Seasonally waterlogged lands are generally peaty (with about 1-2 ft of organic material at the surface) rego gleysols (pH about 4) where the surficial morainal or lacustrine deposits are thick, and gleyed gray luvisols where Devonian calcareous shales and limestones are close enough to the land surface to influence the soil, giving near-neutral pH values and some translocation of clay down the profile. Low beach lines, locally delineating the periphery of lacustrine deposits, or morainal ridges of various origins, are usually a little better drained, with gleyed eutric brunisols or brunisolic luvisols. Where there are reticulate patterned bogs (so-called "fens"), the soils are mostly mesisols of partly humified, thick organic deposits, locally hydric mesisols or "floating bogs".

Trees on these waterlogged flat lands are generally smaller than on freer-drained mineral soils, more openly spaced and with a rich, mossy ground flora containing plume-moss and *Sphagnum* spp. These treed areas merge into open "wetlands" with widely scattered black spruce, tamarack (*Larix laricina* (Du Roi) K. Koch) and white birch. Often these trees cluster with balsam poplar on slightly raised and less wet parts, leaving intervening areas mostly barren except for a shrub layer, sometimes thick, or dwarf birch (*Betula glandulosa* Michx.) with willow and ericaceous species in a sphagnaceous carpet (e.g. *Sphagnum fuscum* (Schimp.) H. Klingr. and *Sphagnum rubellum* Wils.). In turn, these shrubby areas locally merge into sedge flats (notably tufted bog-cottongrass (*Eriophorum spissum* Fern.) with *Sphagnum* spp. and reticulate-patterned bogs, These bogs may exhibit a polygoid pattern of banks on flats, the banks sometimes confining pools, and merging into concentric arcs on slopes.

Though generally unfrozen in summer, local frozen patches of subsoil were observed. The incidence of frozen ground is greater on treed "islands" surrounded by waterlogged land, than on forested land in Land System 2. In some areas, clearly identifiable on the 1:250,000 topographic base maps (south of Fort Simpson and either side of the Mackenzie River near Camsell Bend) there are abundant thermokarst lakes, especially where there are silty lacustrine deposits, often with dead or dying trees leaning over the water and slumping in with parts of the banks, implying that lakes are currently enlarging. Locally, especially in the south and east of the study area, presumably cryostatic pressure generated during autumnal freezing forces alkaline material from the underlying calcareous rock strata into lakes where the substrate does not generally freeze in winter, producing water bodies which are, apparently, largely devoid of plant life.

6.1.5 *Land System 4*: seasonally waterlogged lands with near-surface permafrost (Figs. 12, 19 and 20).

The soils, vegetation and terrain patterns of this Land System are essentially similar to those for Land System 3, but frozen subsoil is encountered by probing much more frequently in summer. The presence of a summer permafrost table at a depth of about 45 inches, locally occurring nearer the surface, produces local patches of sphagnum with lichen, which gives a faint "marbloid" effect on air photographs, and a generally lighter tone in contrast to the generally darker tone characterizing Land System 3. In areas of lacustrine deposits where there are many lakes (in the northwest of the study-area near Fort Norman and Fort Good Hope), subsidence of the partly frozen banks and dying trees into the water is more pronounced than in Land System 3.

6.1.6 *Land System 5:* drumlinoid terrain and intervening seasonally waterlogged lands, locally with near-surface permafrost (Figs. 13 and 14).

The soils and vegetation associated with drumlinoid ridges are the same as for Land System 2 (or Land System 7 at high altitudes in the north of the study area), and the soils and vegetation associated with the intervening seasonally waterlogged lands are locally the same as for the similar lands of Land System 3. However, an effect of numerous, often closely adjacent ridges confining the depressions between them often appears to be the production of a cold microclimate in the depressions, which locally gives rise to a frozen subsoil as in Land System 4, where sphagnum and lichen are intricately patterned. Within the environment of Land System 5, a mineral soil with frozen substrate occurs further south in the study area than in any other Land System.

Terrazoid-patterned peaty lands

6.1.7 *Land System 8*: peat plateaus with labrador tea (*Ledum palustre* L.), locally with near-surface permafrost, and scattered depressions containing summer pools (Figs. 11 and 17).

This system includes frozen, raised peat, low plateaus, usually cryic mesisols, sometimes cryic fibrisols ("peat" of the Geological Survey). Numerous depressions containing summer pools scattered across the peat landscape give the terrain its characteristic "terrazoid" appearance. Dwarfed black spruce, with some tamarack and white birch, and a few jack pine trees are widely scattered across the terrain. A profuse growth of labrador tea (with only subordinate, poorly growing lichen) imparts to the raised peat a dark color in air photographs, contrasting with the light color (sometimes *Sphagnum squarrosum* Crome) around depressions. The flora also includes shrubby cinquefoil (*Potentilla fruticosa* L.), cowberry *Vaccinium vitis-idaea* L.), bake-apple (*Rubus chamaemorus* L.) and horsetails (e.g. *Equisetum* spp.).

The surface of the raised peat displays polygoid cracking, individual polygons being about 2-3 ft in diameter. Probing into cracks usually reveals frozen peat at about 20-30 inches. In addition to this small-scale cracking, there is often a large-scale cracking radiating from a central high point on the peat plateau. If the foci of these radiating cracks are sufficiently open, summer thawing produces damp, sphagnaceous depressions, and sometimes small pools. The depressions grade from small to large, and around the larger depressions with pools there are often concentrically aligned cracks. Cracking and slumping of peat blocks into the depressions produces the very typical dead or dying trees which lean over, and eventually subside into the depressions, implying that these are thermokarst depressions, enlarging and encroaching on the raised peat.

Land System 8 occurs in the south of the study-area. Generally there is a discontinuity between this land system and Land System 3, though locally there is a transition from raised peat with depressions, to larger depressions with frozen, raised peat confined to banks dividing adjoining depressions. Gradually the less prominent banks are thawed to a greater depth, ultimately merging into reticulate, polygoid bogs (Crampton, 1973).

6.1.8 *Land System 9*: hummocky, peaty mineral soils with near-surface permafrost (Figs. 12 and 18).

The soils are cryic peaty regosols with the permafrost at a depth of about 30 inches, merging into turbic peaty regosols. In actively-heaving turbic regosols the land surface is hummocky, the hummocks (about 4 ft across) being defined by a system of polygonal cracks. Presumably, organic matter moved down the cracks, obliquely down the summer surface of the permafrost, and upwards through a central orifice which pierces the vegetative mat, spilling out onto the land surface. Though this surficial exudation onto domed hummocks was observed in high altitude, non-peaty mineral soils in the Mackenzie Mountain Land Region 1, it was not observed in any Land System 9 terrain in the study area, and so it is probably dominantly a fossil structure in the latter terrain, suggestive of colder conditions in the past. There is every graduation from an undisturbed cryic regosol soil profile over the permafrost on flats, especially in the east of the study area (where Land System 9 merges into, and is intricately patterned with Land System 4 terrain), to well-structured turbic regosols which are usually located in the northwest of the study area and on gently sloping land adjoining flats. Though the vegetation is continuous over domed hummocks in the study area, trees which have chanced to grow near cracks eventually become unstable and lean , to give the "drunken forest" effect. Though average depths are given for the summer permafrost table, it follows from the description that this table can be highly irregular in depth, shallowest below cracks, deepest below hummocks.

The black spruce trees are about 15 ft high, growing in an open forest, with a ground vegetation richly colored by lichen, accompanied by ericaceous shrubs such as labrador tea, cowberry, shrubby cinquefoil, dwarf

birch and willows. Sphagnum-rich depressions with sedges, often containing summer pools, are scattered across the land surface.

6.1.9 *Land System 10*: hummocky peat plateaus with lichen and near-surface permafrost, and scattered depressions containing summer pools (Figs. 19, 20 and 24).

The frozen, peat flats of this Land System differ from Land System 8 in that the surface hummocks are more pronounced, there may also be polygoid cracking about 30 ft in diameter, the trees are dwarfed to the extent that they are part of the shrub layer, the ground vegetation is richer in lichens than in any other land system, and the summer permafrost table is close to the surface, often within 10 inches. The tonal contrast on air photographs is the reverse of that for Land System 8; in Land System 10 the lichen-rich, frozen peat is much lighter than the sphagnum-rich depressions. Sphagnum-filled runnels often lead away from the depressions, following courses largely dictated by a polygoid pattern, though many runnels do not link up with any regional drainage system.

Linear-patterned slopes

6.1.10 *Land System 6*: steep, lineated slopes without near-surface permafrost (Figs. 14 and 15).

On most slopes in the south of the study area, and on long, moderately inclined slopes dropping from the high plateau-lands in the centre of the study area, there is a sub-parallel drainage pattern of shallow runnels oriented downslope. The smallest runnels are about 50 yards apart, and the largest about 600 yards apart. Peaty (about 12-18 inches thick) rego gleysols occur on the more gently inclined lower slopes, and gleyed gray luvisols on the more steeply inclined upper slopes where the Devonian and Cretaceous calcareous shales are covered by thinner surficial deposits. The vegetation is similar to Land System 3. Most tree growth occurs in the runnels, making them obvious on air-photographs. Much of the remaining land is wet and comparatively barren of trees, with a ground vegetation of sphagnum and sedges. However, in places there is a very prolific shrub growth of birch and willows. The summer permafrost table occurs at about 40-60 inches, nearest the surface under ridges.

6.1.11 *Land System 11*: gentle, coarsely lineated slopes with near-surface permafrost (Figs. 18 and 21).

On moderate slopes of plateau-lands there is a finely lineated drainage pattern of sub-parallel runnels, generally closer than is typical of Land System 6. The soils are mostly peaty cryic gleysols, with the summer permafrost table at about 20 inches. Dwarfed black spruce (around 15 ft high) is widely scattered across the landscape, often slightly concentrated in the more moist runnels where the summer permafrost table

is deeper and there is a carpet of "cushion" *Sphagnum* spp. On low ridges between the runnels, lichen grows profusely, accompanied by labrador tea, dwarf birch, cowberry and shrubby cinquefoil.

6.1.12 *Land System 12:* gentle, coarsely lineated slopes with near-surface permafrost (Figs. 21 and 24).

On these gentle slopes the organic layer is thicker (about 3 ft) than in Land System 11, some of the sub-parallel runnels are wider than others, and the ridges between runnels are more prominent. There is also a correspondingly greater contrast between lichen-covered ridges and sphagnum-filled runnels. Club-topped, very stunted black spruce is widely scattered. Snow drifts accumulate in the drainage channels, and are preserved for longer during snow-melt on the north-facing slopes. Polygoid cracking and associated hummock development beneath the organic layer occurs, though, as in Land System 9, no surficial spilling of the substrate was observed and so, presumably, this is a fossil structure. There is a considerable variation in the thickness of the active layer, the summer permafrost table being deepest below the more prominent drainage channels, and most shallow (about 10 inches) below cracks defining the ridge hummocks. Land System 12 occurs mostly on northwest-, north-, northeast-, and east-facing slopes, generally on the east side of mountain ranges.

6.1.13 *Land System 13:* rocky plateaus, and finely lineated slopes with near-surface permafrost (Figs. 16, 22 and 23).

Where the morainal veneer is sufficiently thin, the structure of the underlying rock is reflected through the surficial lithic regosols, often giving a quasi-reticulate, major drainage pattern. The morainal cover is thicker on slopes, where there is a finely lineated drainage pattern of sub-parallel runnels, similar to that characterizing Land System 11. The soils, vegetation and active layer characteristics are also similar on slopes to Land System 11, but above the slopes, although the rocky substrata may be cold, it does not often contain ice.

6.1.14 *Land System 14:* hilly moraine and finely lineated slopes with near-surface permafrost (Figs. 23 and 24).

At the northeast foot of the Mackenzie Mountains in the north of the study area there are "humped" or hilly moraines, with richly lichen-covered tops, and finely lineated slopes similar to those of Land System 11. On the hill crests there are cryic regosols with a summer permafrost table very close to the land surface.

6.2 Distribution of Land Regions.

The profound climatic change from south to north across the study area is indicated by the presence on freer-drained sites, in the south of soil profiles in which chemical weathering is occurring, and in the north of soil profiles in which physical weathering is dominant. Podzolization is maximal in the southernmost Trout Lake Land Region 6, and cryoturbation most common in the alpine tundra of the Mackenzie Mountain Land Region 1 which occurs on mountain plateau tops in the northwest of the study area. The Carcajou Canyon Land Region 2 in which freer-drained terrace soils are generally frozen, also occurs in the northwest where the Mackenzie Mountains impinge on the study-area. There is an "outlier" of Land Region 2 on high plateau land northwest of Wrigley and east of the Mackenzie River. The Horn Plateau Land Region 3 occurs in mountainous plateau lands elsewhere along the western margin of the study area, and to the east of the Mackenzie River on the Norman and McConnell Ranges, the Ebutt Hills and Horn Plateau. Except where there are mineral soils, the summer permafrost table is near the land surface. "Outliers" of Land Region 3 occur on the top and north slopes of the Martin Hills, and even as far south as cool, northeast slopes overlooking Trout Lake.

Seasonally waterlogged lands (Land Systems 3 and 4, together occurring in 37% (Fig. 6) of the total study area, in the Fort Simpson and Norman Wells Land Regions 5 and 4, respectively) follow the River Mackenzie throughout its course across the study area, with just one break in continuity north of Wrigley where mountain slopes press in on either side of the river. The belt of this land is widest in the southeast, narrowing northwards. In the north the extent of seasonally waterlogged lands is restricted by mountains on the west side of the river, but it is moderately extensive on flat lands on the east side of the study area.

Considered separately, Land Region 4 occurs in lowlands either side of the Mackenzie River north of Wrigley, and along the eastern border of the study area, as far south as on the north side of the Horn Plateau. Land System 4 is seasonally waterlogged land with near-surface permafrost (absent in Land System 3), and its presence in cold, depressed land south of Horn Plateau (together with unusually lichenous Land System 8) gives rise to an "outlier" of Land Region 4. Land Region 5 occurs in lowlands either side of the Mackenzie and Liard Rivers, and encircles Horn Plateau. Like Land Region 4, Land Region 5 becomes more extensive south and east of the study area. Great Bear and Great Slave Lakes near to the east appear to have created a local climate distinctly different from that created by the Mackenzie Mountains to the west of the study area. Land Region 6 is restricted to the south of the study area. The proportions of each Land Region in the total study area is shown in Fig. 7.

6.3 Distribution of Land Districts

Silty-clayey morainal deposits (Land District 1) are most widespread in the east and south of the study-area, away from the rivers. Locally, (only 3% of total morainal deposits - Fig. 7), the deposits are sandy or gravelly (Land District 2), as on the north side of the Cameron Hills. Silty-clayey lacustrine deposits (Land District 3) occur either side of the Liard and Mackenzie Rivers in the south; remnants of one large glacially impounded lake. Another, separate lake was impounded in the north, and gave rise to more extensive lacustrine deposits. Locally, (14% of total lacustrine deposits - Fig. 7), the deposits are sandy and gravelly (Land District 4). In the areas of both glacial lakes the lacustrine material was very locally resorted during post-glacial times by wind, to form areas of sand dunes (Land District 5). A morainal veneer over bedrock is most extensive in the mountainous area (Land District 6).

6.4 Distribution of Land Systems.

In Land Regions the sequence of numbered Land Systems is broadly that of susceptibility to surface damage from unconcerned traffic, 1 being the least susceptible and 14 the most susceptible. If the Land Systems are grouped by terrain similarity (Fig. 6), within each group the distribution-pattern is generally that of the less-easily damaged lands being recorded mostly in the sothernmost Land Regions, and the more-easily damaged lands being recorded mostly in the northernmost or most elevated Land Regions. Linear-patterned slopes illustrate this distribution, steep lineated slopes without near-surface permafrost (Land System 6) being most extensive in the most southerly Trout Lake Land Region 6, and progressively less extensive northwards and at higher elevations, to Horn Plateau Land Region 3. These slopes have not been observed in the Mackenzie Mountain and Carcajou Canyon Land Regions 1 and 2. In contrast, rocky plateaus with finely lineated slopes and near-surface permafrost (Land System 13) have not been recorded in the southernmost Trout Lake and Fort Simpson Land Regions 6 and 5, but although generally extensive in the Horn Plateau and Carcajou Canyon Land Regions 3 and 2, they are most extensive in the northwestern,high-altitude Mackenzie Mountain Land Region 1. Moderate, finely lineated slopes with near-surface permafrost (Land System 11) are most extensive in the Horn Plateau Land Region 3, and gentle, coarsely lineated slopes (Land System 12) are most extensive in Carcajou Canyon Land Region 2.

Similarly, considering terrazoid-patterned lands, frozen peat plateaus with labrador tea (Land System 8) are most extensive in the southernmost Trout Lake Land Region 6, whereas frozen peat plateaus with lichen (and a summer permafrost table nearer to the land surface) (Land System 10) are most extensive in the Carcajou Canyon Land Region 2. In the north of the study-area, Land System 10 grades into Land System 14 as the terrain becomes more hilly and the slopes lineated, and Land System 14 is, likewise, most extensive in the Carcajou Canyon Lake Region 2.

Land Regions in total study area

Mackenzie Mountain	Carcajou Canyon	Horn Plateau	Norman Wells	Fort Simpson	Trout Lake
1	2	3	4	5	6
1%	5%	30%	16%	22%	26%

Land Districts in total study area

silty-clayey morainal	sandy-gravelly morainal	silty-clayey lacustrine	sandy-gravelly lacustrine	eolian	shallow bedrock
1	2	3	4	5	6
64%	2%	14%	2%	1%	17%

Fig. 7. % of Land Regions and Land Districts in total study area.

Seasonally waterlogged lands without near-surface permafrost (Land System 3) are most extensive in the southern Trout Lake and Fort Simpson Land Regions 6 and 5, whereas similar lands, but with near-surface permafrost (Land System 4), are most extensive in the Norman Wells Land Region 4 to the north. In land Region 4, differences in the depth of the active layer determines whether surficial waterlogging can occur in summer. If the summer permafrost table is too near the land surface, the surface is, relatively, drier and lichen replaces *Sphagnum* as the dominant element in the vegetation (Land System 9). Hence, Land System 4 interdigitates with Land System 9 in the Norman Wells Land Region 4, a phenomenon displayed particularly well in the northwest of the study-area. At progressively higher elevations and latitudes, from the Norman Wells Land Region 4 to the Carcajou Canyon Land Region 2, seasonally waterlogged Land System 4 is gradually replaced by Land System 9 with a shallow active layer.

Likewise, freer-drained mineral soils without near-surface permafrost (Land System 2) are also most extensive in Land Regions 6 and 5, whereas such soils but with near-surface permafrost (Land System 7) are most extensive in the Carcajou Canyon Land Region 2 in the northwest of the study-area. Rock outcrops are most extensive in the Mackenzie Mountain Land Region 1.

Forested, freer-drained mineral soils without near-surface permafrost (Land System 2) are most extensive on sandy-gravelly morainal deposits (such as eskers - Land District 2), and on silty-clayey lacustrine deposits (adjoining river banks - Land District 3) (Fig. 6). In the Fort Simpson Land Region 5, seasonally waterlogged lands without near-surface permafrost are more extensive on sandy-gravelly lacustrine deposits (90% of total area of Land District 4) than on the silty-clayey textured lacustrine deposits (64% of total area of Land District 3). Conversely, in the same Land Region 5, frozen peat plateaus (Land System 8) occur in 13% of the total area of silty-clayey lacustrine deposits, contrasted with less than 1% of the total area of sandy-gravelly lacustrine deposits. In the Norman Wells Land Region 4, frozen peat plateaus (Land System 8) and frozen peaty mineral soils (Land System 9), together, occur in 14% of the total area of silty-clayey lacustrine deposits, whereas in sandy-gravelly lacustrine soils these frozen lands occur in less than 1% of the total area. Since, as described previously, the proportion of sandy-gravelly land is greater on lacustrine deposits than on morainal deposits, and, as described above, frozen organic or mineral soils are less extensive on sandy-gravelly terrain, the distribution of sandy-gravelly lacustrine deposits within the Mackenzie Valley is an important consideration for lines of transportation.

On silty-clayey morainal deposits (Land District 1 - the most common parent material in the study-area), the percentage of land with near-surface permafrost increases from 24% of the total area of Trout Lake Land Region 6 in the south, through 28%, 42%, 75% in Land Regions 5, 4 and 3, to 82% of the total area of Carcajou Canyon Land Region 2. On this parent material the proportion of lichenous, terrazoid-patterned, peat plateaus (Land System 10) increases from 4% in the Norman Wells Land Region 4, through 10% in Land Region 3, to 20% of the total area of Carcajou Land Region 2. This confirms the regional trend already alluded to, of an increasing proportion of land susceptible to damage from uncaring traffic, northwards and at greater latitudes.

Rocky plateaus with finely lineated slopes and near-surface permafrost (Land System 13) are most extensive in the Horn Plateau Land Region 3 where there is a veneer of silty-clayey morainal deposits over shallow bedrock (43% of the total area of Land District 6, compared with 28% of actual rock outcrops). The proportional extent of Land System 13 decreases with greater altitude (34%, compared with 38% of rock outcrops in Land District 6), until it is 26% of Land District 6 in the Mackenzie Mountain Land Region 1, compared with the great area (65%) of rock outcrops.

Though Land System 2 is generally most suitable land for transportation lines, some of it is found near unstable banks, and it occurs in only 8% of the total study area. Some frozen land also often occurs on the cool, north and northeast sides of normally treed morainal ridges (Fig. 11). The importance of aspect increases northwards.

6.5 Susceptibility of terrain types to damage

Based on observations of seismic and road lines, campsites and post-fire conditions throughout the study-area, with probing to detect the depth to the summer permafrost table inside and outside the disturbed land, the Land Systems (1-14) have been arranged in an approximate order of susceptibility to surface damage from unconcerned traffic. However, local conditions can change the relative position of Land Systems in this sequence, and so the fourteen landscape units have been assigned to four groups; least susceptible, moderately susceptible, strongly susceptible and most susceptible to damage. Rock outcrops (Land System 1) and mineral soils (Land System 2) are least susceptible, though in areas of silty lacustrine deposits, local ice masses situated too deep to have any effect on the surface vegetation (about 5 ft or more), can melt if the forest is cut-over and the land greatly disturbed, or if a river erodes its banks to expose such ice masses. Ice-melt can cause considerable subsidence and pooling of water, or slumping of banks. Seasonally waterlogged lands without near-surface permafrost (Land System 3) are, equally, not susceptible to damage unless, again, the land surface is greatly disturbed, beyond the formation of normal rutting, and if local ice masses happen to be present in silty lacustrine deposits. These hazards are more likely to be experienced north of latitude 61°31'.

Seasonally waterlogged lands with near-surface permafrost (Land System 4, contrasted with 3) are more easily damaged by land disturbance or by fire, especially where these lands slope down to rivers. Removal of the surface vegetation and disturbance of the organic layer can cause lowering of the summer permafrost table, and if the land is sloping, slumping can occur. In drumlinoid terrain (Land System 5) most land with near-surface permafrost occurs in the hollows between ridges, intricately distributed with land not having near-surface permafrost; it is this local variability that creates a moderate hazard. Though the active layer may be up to 60 inches deep in Land System 6, the slopes constitute a potential hazard for erosion, and so these lands are also considered moderately susceptible to damage.

Flat or undulating mineral soils (Land Systems 7 and 9) or organic terrain (Land Systems 8 and 10) are considered strongly susceptible to surface damage from uncaring traffic because, in summer, "high-ice" permafrost occurs close to the land surface. Local piercing of the insulating vegetative and organic cover is sufficient to cause ice-melt and subsidence. On flats this man-induced subsidence may merge into natural subsidence depressions (Fig. 8), or large pools may form, but near slopes, even gentle slopes down to rivers, an increase in the depth of the active layer, charged with water, can produce slumping (Fig. 8).

Lands considered most susceptible to damage are those which, by definition, are generally sloping and in summer have "high-ice" permafrost near the land surface (Linear-patterned Land Systems 11, 12, 13 and 14). Fragmentation of the surface vegetative and organic cover by traffic quickly produces subsidence and slumping or gully erosion (Fig. 8). This style of terrain damage is often self-perpetuating, as slumping or erosion exposes more of the permafrost, to cause more melting, subsidence and erosion, until the slopes have been sufficiently reduced in steepness for the vegetation to begin to re-establish itself, and until the banks delineating the damaged area are sufficiently low for the vegetative mat on the undamaged land to drop and cover them.

7 DISCUSSION

7.1 Correlation with F.M.I.'s current vegetation survey

A more sensible correlation of Land Systems with the current vegetation survey was gained when the Land Systems were grouped according to Fig. 6. The correlation was based on a count of Standard Mercator Grid intersections. On this basis the freer-drained mineral soils were associated mostly with "thrifty" white spruce, jack pine, aspen and white birch stands of fire origin, with a shruby, herbaceous (grassy) ground vegetation; an older successional stage of this unit, usually with a feather moss ground vegetation; and to a lesser extent, with slow-growing, narrow-crowned black spruce rarely exceeding 50 ft in height, with a mossy and ericaceous ground vegetation (Fig. 9).

As often occurs with natural phenomena, the end-parts of this particular stratification of observations were distinctly different, but there was a continuum between the extremes, one part merging into the other. Hence, like the imperfectly drained "freer-drained" sites, the less wet seasonally-waterlogged lands were sometimes associated with black and white spruce stands having a shrubby and, especially, a mossy ground vegetation, but more often with slow-growing, narrow-crowned black spruce with a mossy and ericaceous ground vegetation. The wettest sites were associated with flat, dwarf birch and sedge fen, and sphagnum bog.

Slow-growing, narrow-crowned black spruce with a mossy and shrubby ground vegetation dominates in terrazoid-patterned lands; with much dense lichen accompanied by moss and ericaceous shrubs, below stunted black spruce not exceeding 25 ft in height; and some sphagnum bog.

Fig. 8. Some important aspects of terrain damage after disturbance: bank slumping after fire (top-right): thermal subsidence after line-cut through vegetative and organic layers (bottom-right): gully erosion after similar damage on slope (left).

Description of relevant F.M.I. vegetation classes.

D. Thrifty jack pine, aspen, white birch or white spruce stands (pure or mixed) of fire origin, growing on well-drained upland sites. Species composition dependent on latitude and stage of development. Lesser vegetation consists of sparse to moderate shrub, herb and grass cover.

E. An older successional stage of D. Black and white spruce predominate but aspen and birch may occur as minor components. Lesser vegetation consists of a moderate high and low layer and usually a complete cover of feather moss.

F. Complete deep moss and moderate to sparse low ericaceous shrub cover with occasional patches of lichen. Tree cover, when present, consists of slow-growing, narrow-crowned black spruce which rarely attain heights in excess of 50 feet. This type occurs on poorly-drained upland or lowland organic sites.

G. Dense lichen, moss and sparse to moderate ericaceous shrub growth with sphagnum and sedges in wet depressions. Stunted black spruce and minor amounts of larch may occur as open stands never exceeding 25 feet in height; found on very poorly drained upland flats with peat plateaus interspersed by wet depressions.

I. Dwarf birch-sedge fen, generally flat and very poorly drained.

J. Sphagnum bog, found on a flat very wet (often circular) treeless, thermokarst feature. This type commonly occurs in association with Classes F, G or I.

Susceptibility classes for Land Systems	Proportions (%) of vegetation classes					
	D	E	F	G	I	J
Freer-drained mineral soils	41	39	20			
Seasonally waterlogged lands	7	25	39		15	14
Terrazoid-patterned lands			50	33	5	12
Linear-patterned lands			27	73		

Fig. 9. Correlation of susceptibility classes for Land Systems, with current vegetation classes (of F.M.I.).

Linear-patterned lands contain the greatest extent of dense lichen with moss and ericaceous shrubs below severely stunted black spruce, and some slow-growing and narrow-crowned black spruce with a mossy and shrubby ground vegetation. Presumably, the correlation of lichenous land is with the low-broad ridges between sub-parallel runnels, and mossy, black spruce lands with the runnels. Similar rational interpretations can be made for the other Land System groups, yielding a reasonable correlation between the two surveys, each enhancing the environmental detail for the other.

7.2 Correlation with survey of disturbed sites.

An insufficient number of disturbed sites were examined in the study-area to allow a detailed correlation. However, there was a useful correlation of species that pioneered disturbed sites and the four groups of Land Systems. Grass often pioneered disturbed sites where freer-drained mineral soils occurred on terrace and ridge sites, and sphagnum eventually grew thickly on seasonally waterlogged lands where they had been disturbed. Sedges and willows usually pioneered disturbed sites in terrazoid-patterned lands whereas, because of gully erosion down slopes, vegetation had great difficulty in re-establishing itself in linear-patterned lands.

7.3 Correlation with the Canadian Wildlife Service's survey of wildlife habitats.

The open, gently sloping, black spruce-lichen forest of Land System 12 occurring mostly on slopes facing around northeast, generally to the east of mountain ranges, appears to be a suitable habitat for caribou. The rich lichen vegetation supplies excellent forage. The caribou range associated with, for example, the McConnell Range of mountains extends from east of the Range during early winter, to the basal eastern slopes of the Range during late winter, and possibly on to the Range during summer.

7.4 Relevance of landscape survey to other areas

Some of the results of this study will be applicable to other areas, but it is primarily the methodology developed for the Mackenzie River Valley that has greatest relevance to other areas. A reasonable air-photograph coverage is essential to ascertain the compatibility of results between areas, and to undertake further landscape surveys. The methodology can be kept sufficiently flexible to incorporate such contingencies as a scarcity of surficial geological data, or the need to define new landscape units. However, in the long term it would be convenient if the basic classification structure remained unaltered. The scale at which the final maps are presented can be adjusted to suit the scale of air photography and ground checking. Since the construction of the maps involves aspects of geomorphology, drainage, pedology and vegetation (where relevant), they should form suitable base maps for other work.

8 CONCLUSIONS

The study-area is generally cool, with a small precipitation (about 15 inches per annum). Though it occurs within the so-called "discontinuous permafrost" zone, "continuous permafrost" extends southwards into the study area, encompassing the Mackenzie River at least as far as latitude 63°41'. The tundra occurs at high elevations in the northwest.

Much of the study area is underlain by calcareous strata, though locally sandstones and conglomerates crop out and give rise to distinctive landforms. Till mantles most of the area, except where the Mackenzie Mountains form rugged terrain along the western border. Lacustrine deposits occur either side of the major rivers, one area in the north and the other in the south of the study area.

Maps are necessary to convey efficiently the maximum information to users of the report. They are based on air-photograph interpretation, checked by ground inspection. The maps show the distribution of landscape units, or vegetation-landform patterns that can be identified on air-photographs, and which have significance in terms of the permafrost character. There are four basic kinds of terrain; forested, freer-drained sites; seasonally waterlogged sites with *Sphagnum*; sites with permafrost close to the land surface which have a lichenous vegetation with a terrazoid pattern and low relief; sites with permafrost close to the land surface which have a lichenous vegetation but are linear-patterned and sloping.

The distribution of frozen and unfrozen land was used to climatically zone the study area, a zonation best illustrated by the soil type characterizing the freer-drained sites (alluded to above) in each zone. Horizontally layered, podzolized soils are indicative of a climate in the south, sufficiently warm to allow bio-chemical activity, whereas cryoturbated soils showing a vertical component in profile layering are indicative of a cool climate in the north of the study area where there is not much significant bio-chemical activity in the soil, but much frost-heaving.

Great Bear and Great Slave Lakes to the east of the study area appear to have created a local mesoclimate warmer than that prevailing elsewhere at the same latitudes, and distinctly different from the colder climate associated with the Mackenzie Mountains to the west of the study area.

The basic units delineated by the geologists have been incorporated into the classification, with a particular emphasis on the distribution of fine- and coarse-textured substrates. A greater proportion of the lacustrine deposits are coarse-textured than the morainal deposits, and frozen land is less extensive on coarse-textured deposits.

Seasonally waterlogged lands are most extensive in the south. Landscape units sensitive to damage from uncaring traffic become progressively more widespread northwards. The linear-patterned, sloping lands are liable to be most damaged because gully erosion often follows thermal subsidence as the permafrost table melts and lowers. The re-establishment of vegetation is slow.

9 IMPLICATIONS AND RECOMMENDATIONS

9.1 Relevance to scientific studies

The maps are intended to make as objective as possible the determination of the distribution of different terrain-permafrost relation-

ships. The distribution of these different relationships is used to help zone the study area climatically. Current concepts of the continuous and discontinuous permafrost zones require some modification in the light of this study. The continuous permafrost zone extends southwards on uplands, on both sides of the Mackenzie River, especially on the west side, but not in the vicinity of the Great Bear and Great Slave Lakes east of the Mackenzie River which appear to create their own local mesoclimate.

Maps incorporating aspects of geomorphology, drainage, permafrost, pedology and vegetation must, by their nature, involve many compromises in the character of the information they are intended to convey. To maximize this information without creating contradictions within the classification supporting the maps is the art of map-making. A further constraint to the amount of information that can be conveyed by these maps is their derivation from landscape patterns that can be recognized in air-photographs; a constraint introduced for very practical reasons. However, it is intended that these maps should form the basis for correlations between the several disciplines involved within the Mackenzie Valley study. Where possible, some of these correlations have already been undertaken and have been reported.

Most evidence observed within the study area suggests that the permafrost has been degrading; more so in the south, little in the north of the study area. In generally frozen terrain, summer pools are enlarging and causing the subsidence of blocks of land, carrying trees into the pools and killing them. This is particularly associated with southern lowlands; at one locality north of Fort Simpson an extensive area of once-frozen peat plateau had disintegrated, leaving widely scattered and isolated peat "hags". Also, hummocky terrain extensive in Land System 9 must have originated during some colder period in the past. Now, they are no longer active, but are fossil structures.

This survey was undertaken, in the first place, to augment information collected by the Geological Survey of Canada.

9.2 Relevance to pipeline construction

Although the study area is supposed to occur entirely within the discontinuous permafrost zone (Brown, 1967), this is too simplistic an appraisal. The study area reaches from southern lands near Great Slave Lake where frozen substrate is mostly confined to peat plateaus and where a greater part of the area is relatively permafrost-free, seasonally waterlogged land, to lands in the north of the study area near Great Bear Lake where there is permafrost generally at about 40" depth, to upland areas on both sides of the Mackenzie River where the permafrost occurs close to the land surface. At the highest altitudes in the north there occurs alpine tundra, equivalent to the arctic tundra. Hence, within the study area there occurs every possible mixture of frozen and unfrozen land types, making this part of the Mackenzie River valley highly unpredictible from place to place and so the most vulnerable to damage by uncaring traffic. The results of the study are presented in the form of maps showing the distribution of different terrain types characterized by different permafrost relationships.

The 1:600,000 scale map is intended to give an over-view of the study area, with particular reference to the distribution of four classes of terrain susceptibility to damage. The map is intended for regional planning, and is illustrated as completely as possible so that it can be separated and used independently from the report. It can be used for reconnaissance-type appraisals, and as a precursor to the report and large-scale maps. The three large-scale maps on the scale of 1:250,000 are intended for more precise work. For each delineated area they show the Land System occurring in at least 80% of the whole area. Where a small parcel of land is exceptional, the report contains stereograms and descriptions so that the map-user can determine the true nature of the terrain he is standing on.

9.3 Judged assessments

Recent statements by pipeline and highway constructors indicate that the engineers involved consider that they can use southern techniques at least as far down the Mackenzie River valley as Norman Wells, north of which settlement they anticipate the necessity of increasingly modifying their southern techniques so as not to damage the permafrost terrain. However, this survey reveals that, away from large lakes such as Great Bear, the continuous permafrost zone extends further south than has been previously recorded, and engineers will encounter problems associated with continuous permafrost as far south as latitude 63°40'. In this region slopes with near-surface permafrost, the most easily damaged terrain, encroach seriously on the river valley. If such land is to be avoided, transportation lines will have to be routed either close to the river banks which are, however, liable to slumping because of anthropogenic or natural causes, or near the top of the linear-patterned slopes so as to intersect as little of the downslope linear drainage pattern as possible. If placed on middle or lower slopes, severe ponding will occur on the up-side of the transportation line each spring, with the consequent great risk of wash-outs and thermal effects in the soil, and continuous, heavy maintenance costs. The sub-parallel drainage runnels are sufficiently close in many places, for example, to make the placement of highway culverts an impractical solution.

South of this "high-risk" region, to Fort Simpson at least, though seasonally waterlogged lands are extensive, the scattered presence of areas of terrain with near-surface permafrost requires cautious routing of transportation lines. Some of these frozen lands, in fact, are intricately patterned with and without near-surface permafrost, in a way which excludes the practical possibility of construction technique modification to suit local conditions unless, for example, a continuous berm buries and insulates the highly variable landscape. If such a berm carries a refrigerated line, there may be complications (where insulation is insufficient) of freezing normally unfrozen substrate in the landscape. This would upset the natural drainage established in the landscape by a dynamically evolving system.

Since knowledge of the North is severely limited, especially with regard to precisely what happens after every kind of intervention within natural systems, and still more as to what remedial measures are effective in restoring stability to differently damaged areas, predicting events subsequent to disturbance is speculative. To describe them as speculative is not to imply that they are unimportant; on the contrary, since the knowledge is not available, even greater caution is needed to avoid disturbance of natural landscape systems in the first place.

10 NEEDS FOR FURTHER STUDY

The survey has been based on landform-vegetation patterns that can be identified in air-photographs so that mapping can be extrapolated beyond the study area. Now that work in the study area has been completed, both regarding relevance to scientific studies and pipeline construction, it is highly desirable that this survey is extrapolated into the areas of immediate interest to the goals set for this Mackenzie Valley Study. Outside the area of reasonable extrapolation, further ground checking will be required. It is intended to use the maps, as much as possible, for correlation between different disciplines involved in the area.

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APPENDICES

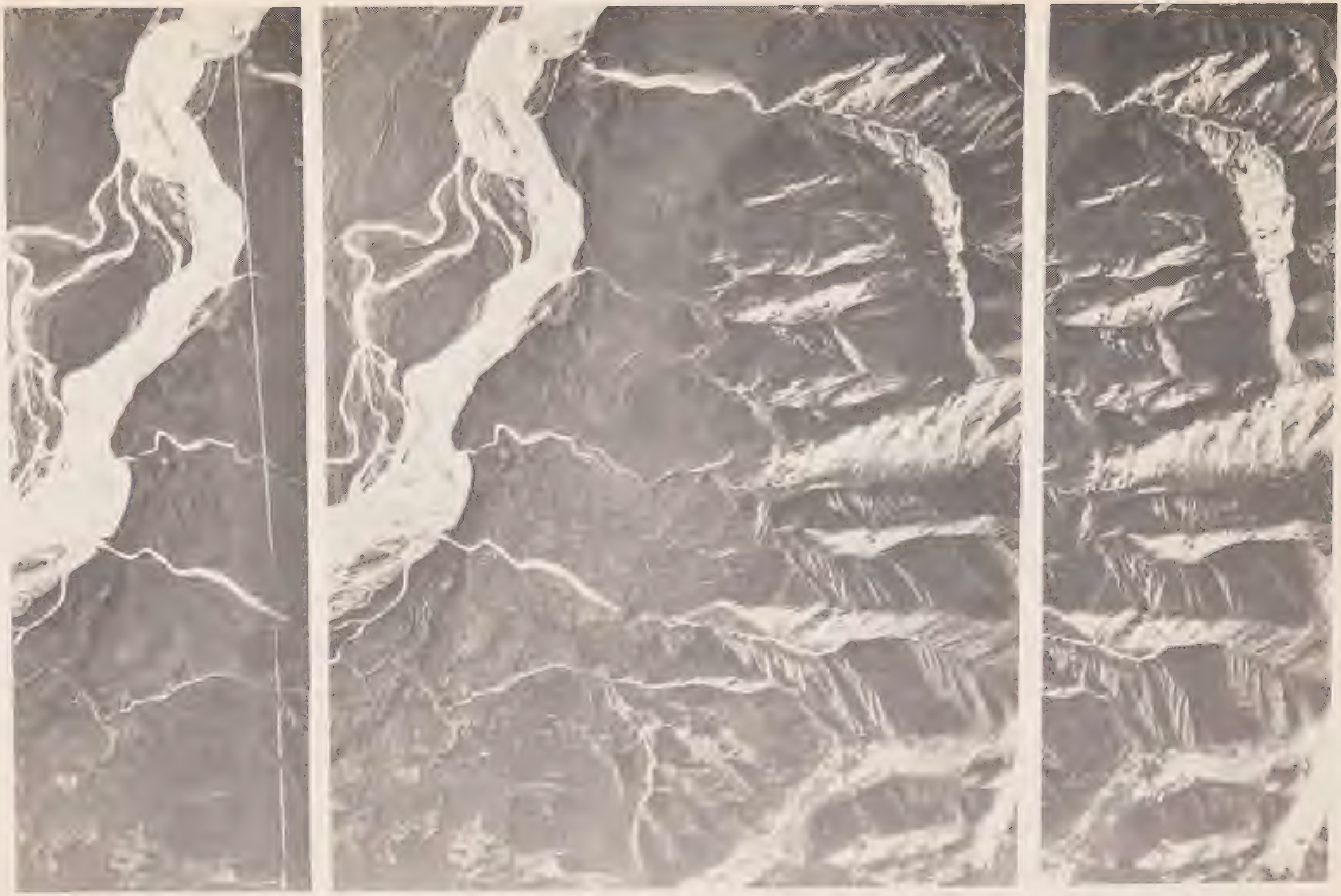
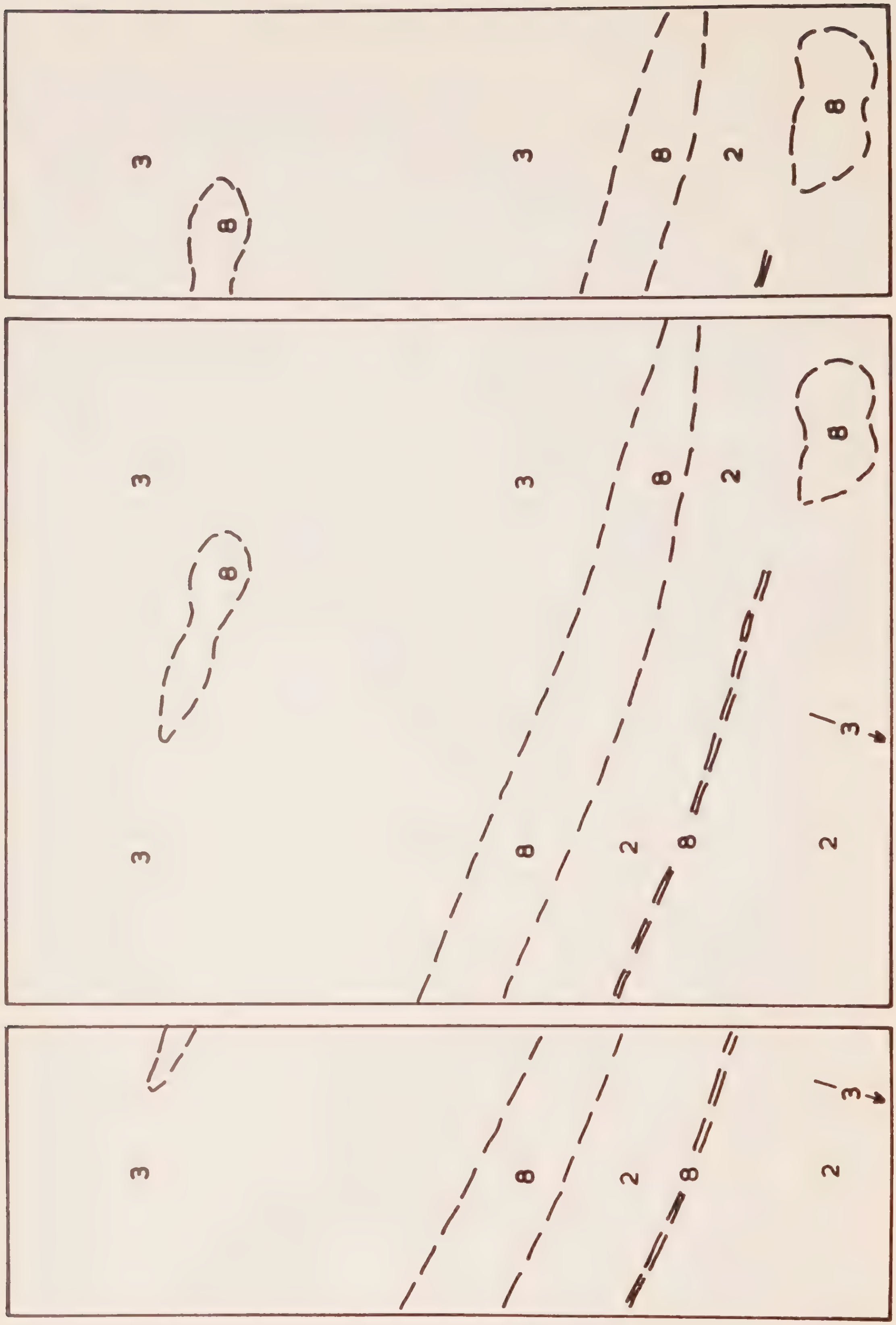


Fig. 10. Stereogram, illustrating principally, landscape units 1 and 2. Parts of air-photographs A17624-50,51,52.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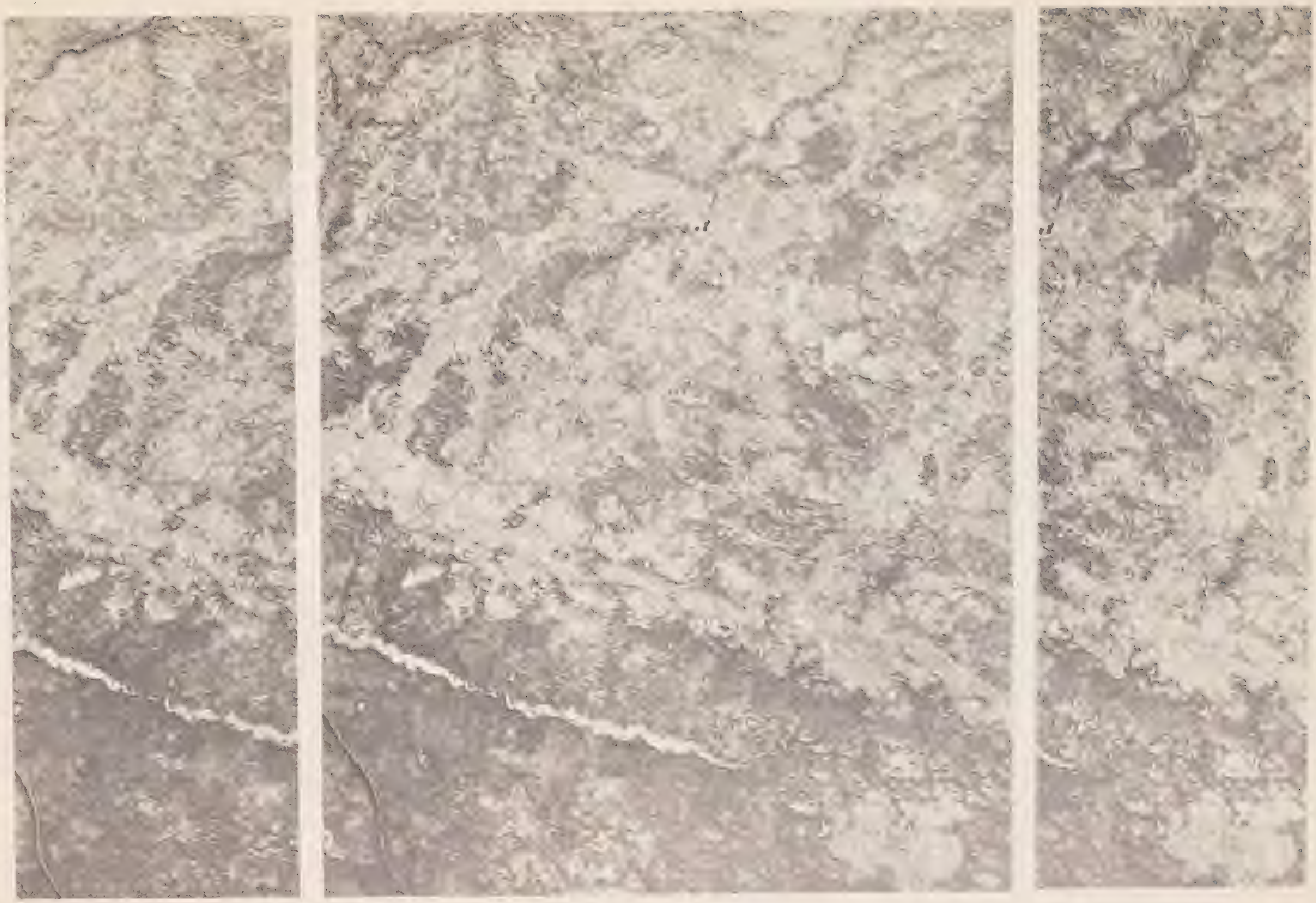
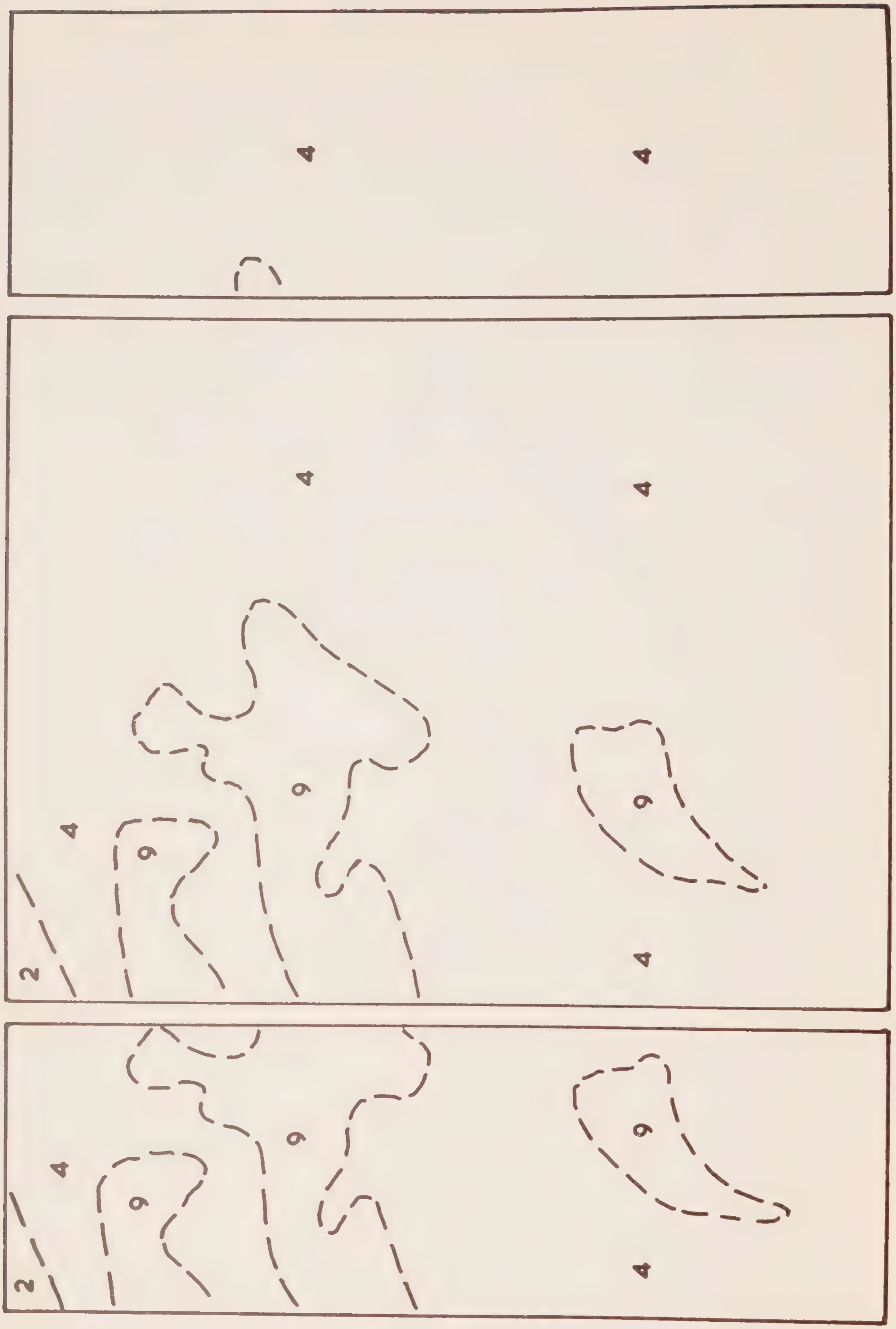


Fig. 11. Stereogram, illustrating principally landscape units 2, 3 and 6. Parts of air-photographs A11029-373,374,375.



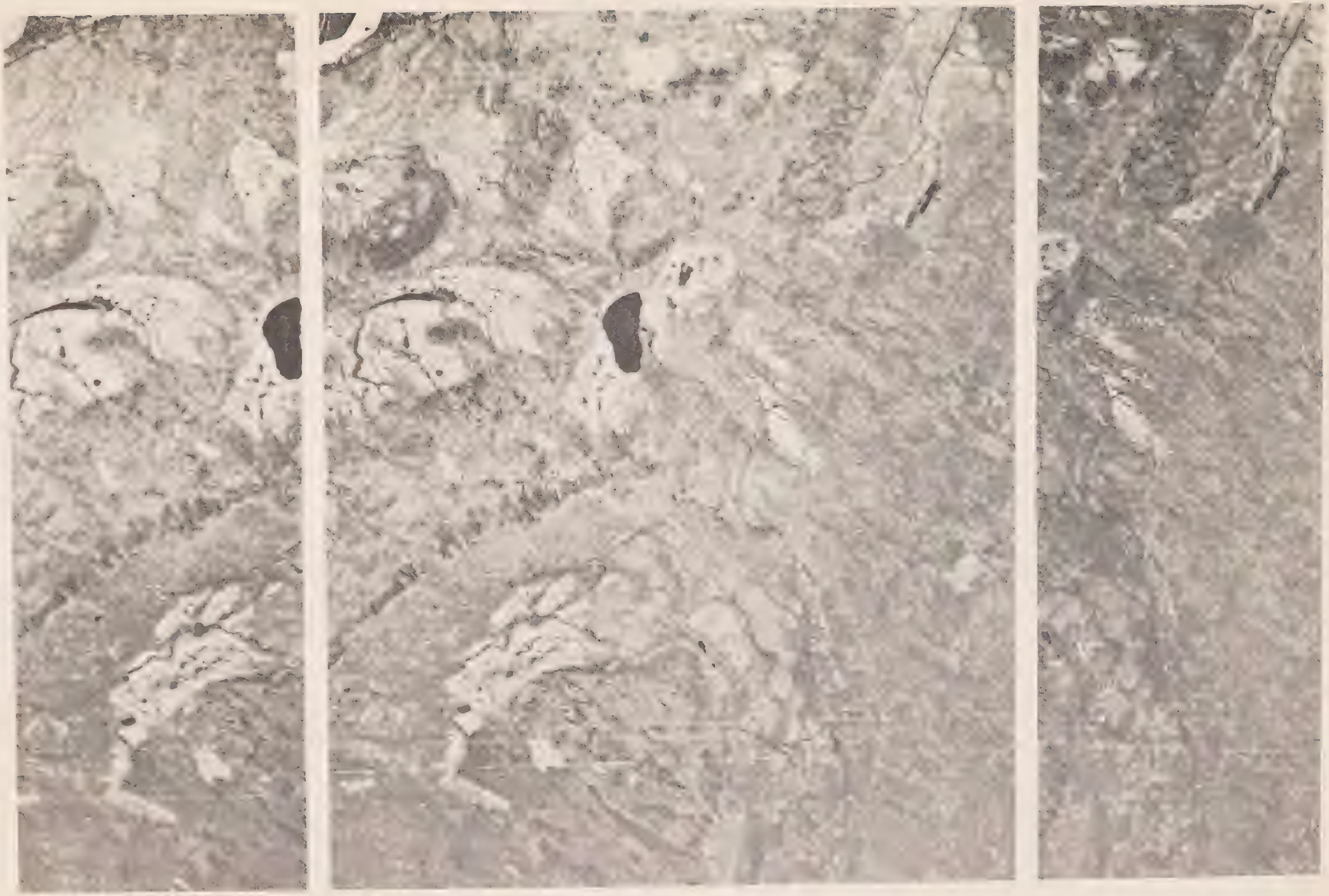
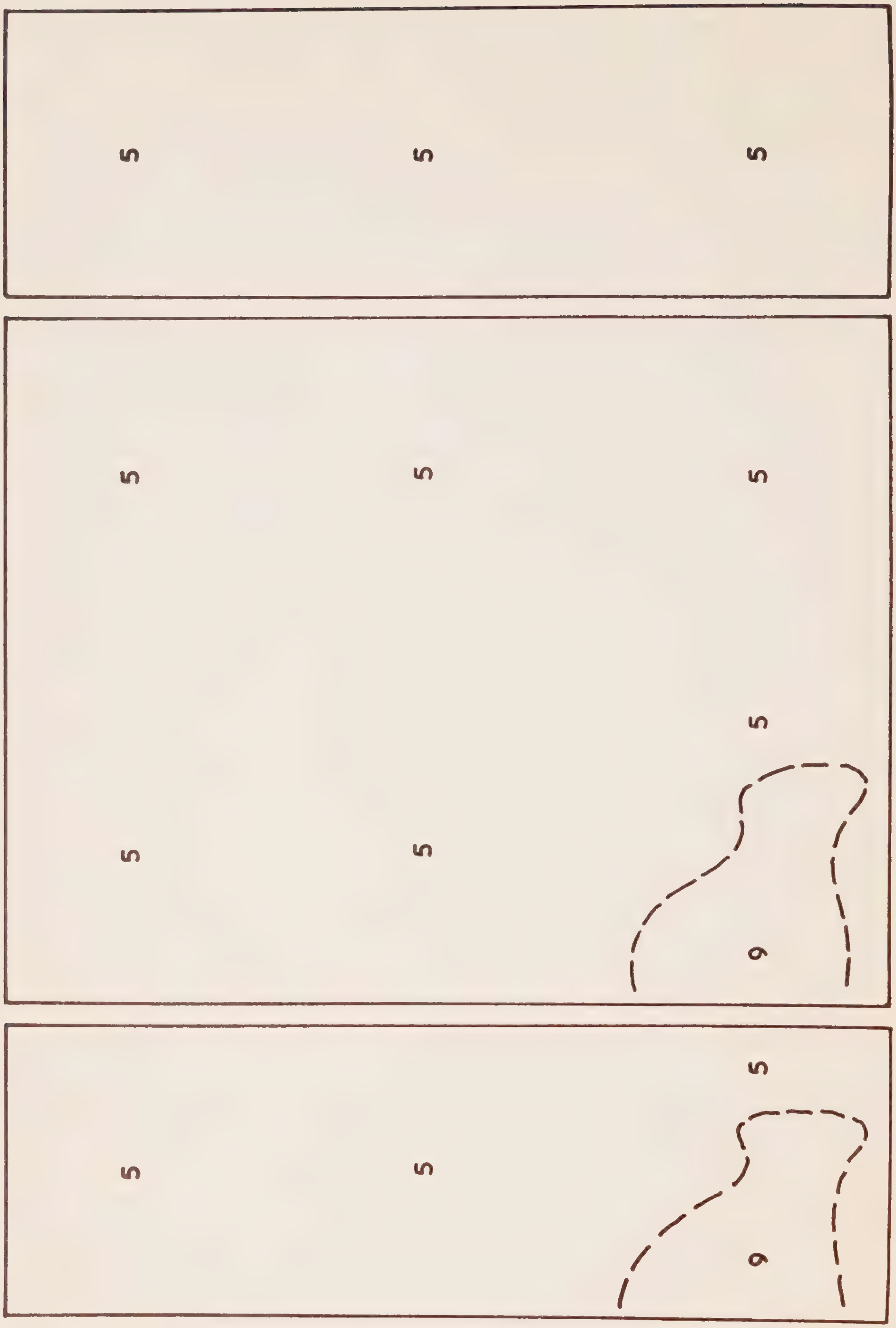


Fig. 12. Stereogram, illustrating principally landscape units 4 and 9. Parts of air-photographs A12149-328,329,330.



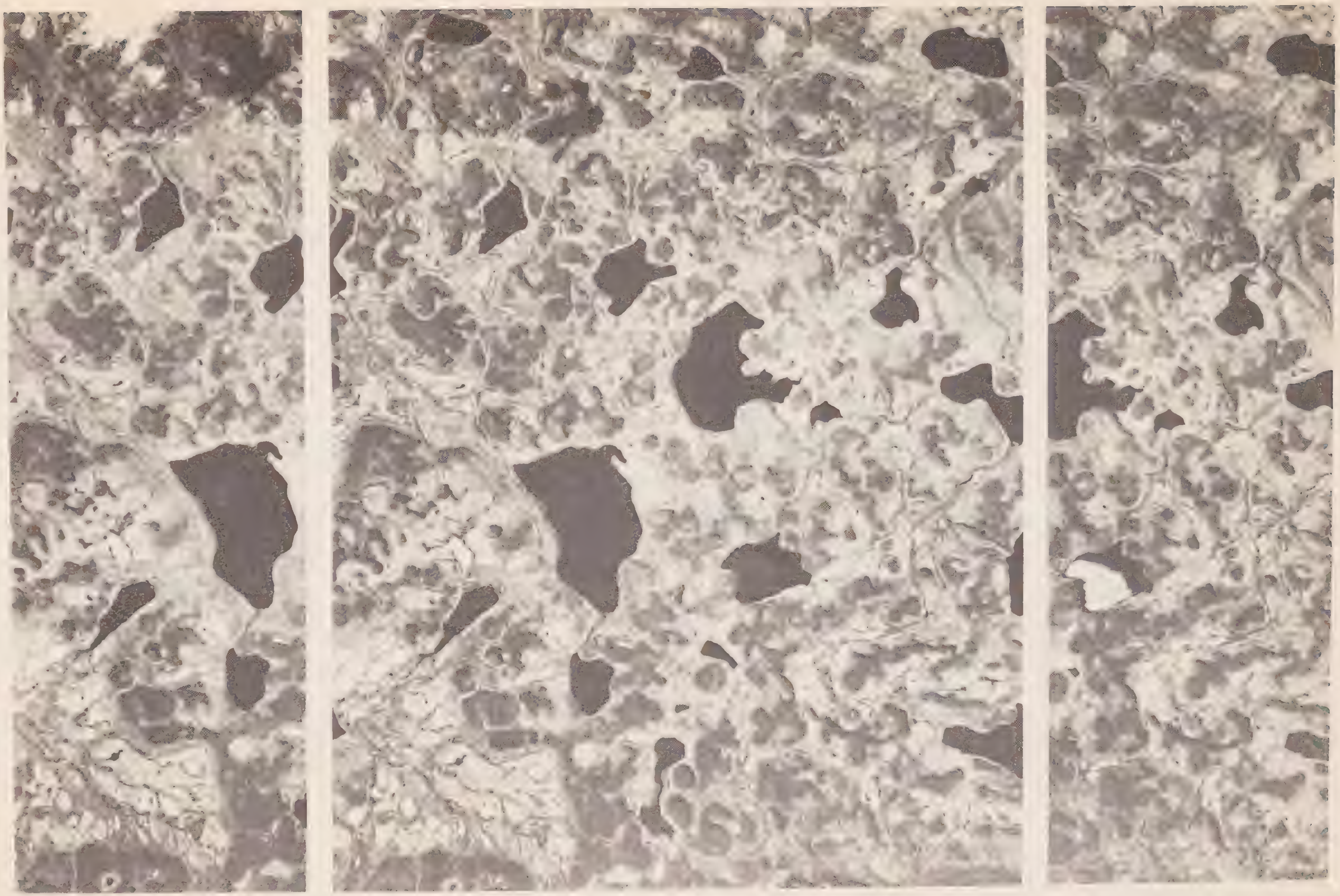
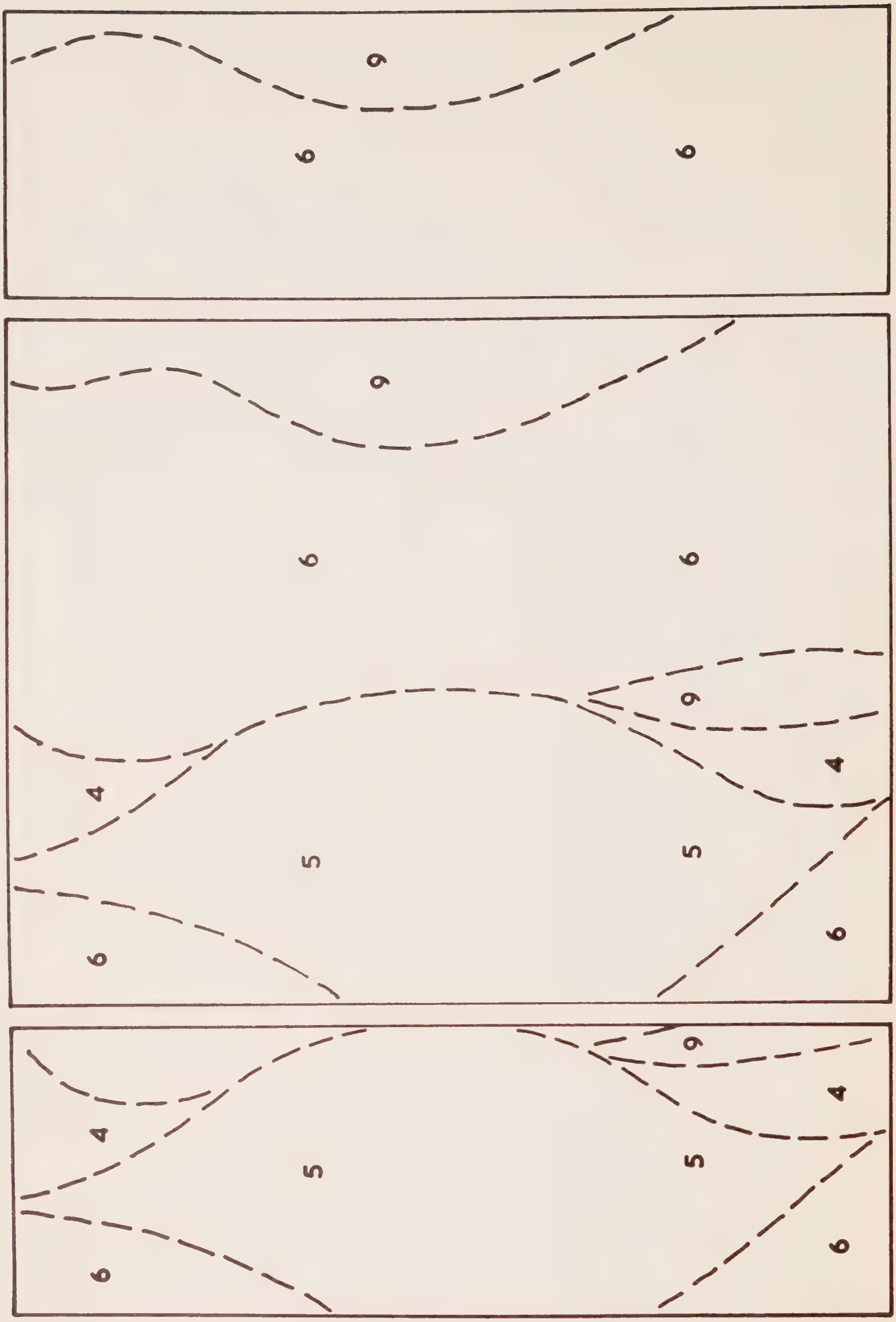


Fig. 13. Stereogram, illustrating principally Landscape Unit 5. Parts of air-photographs A12609-183,182,181.



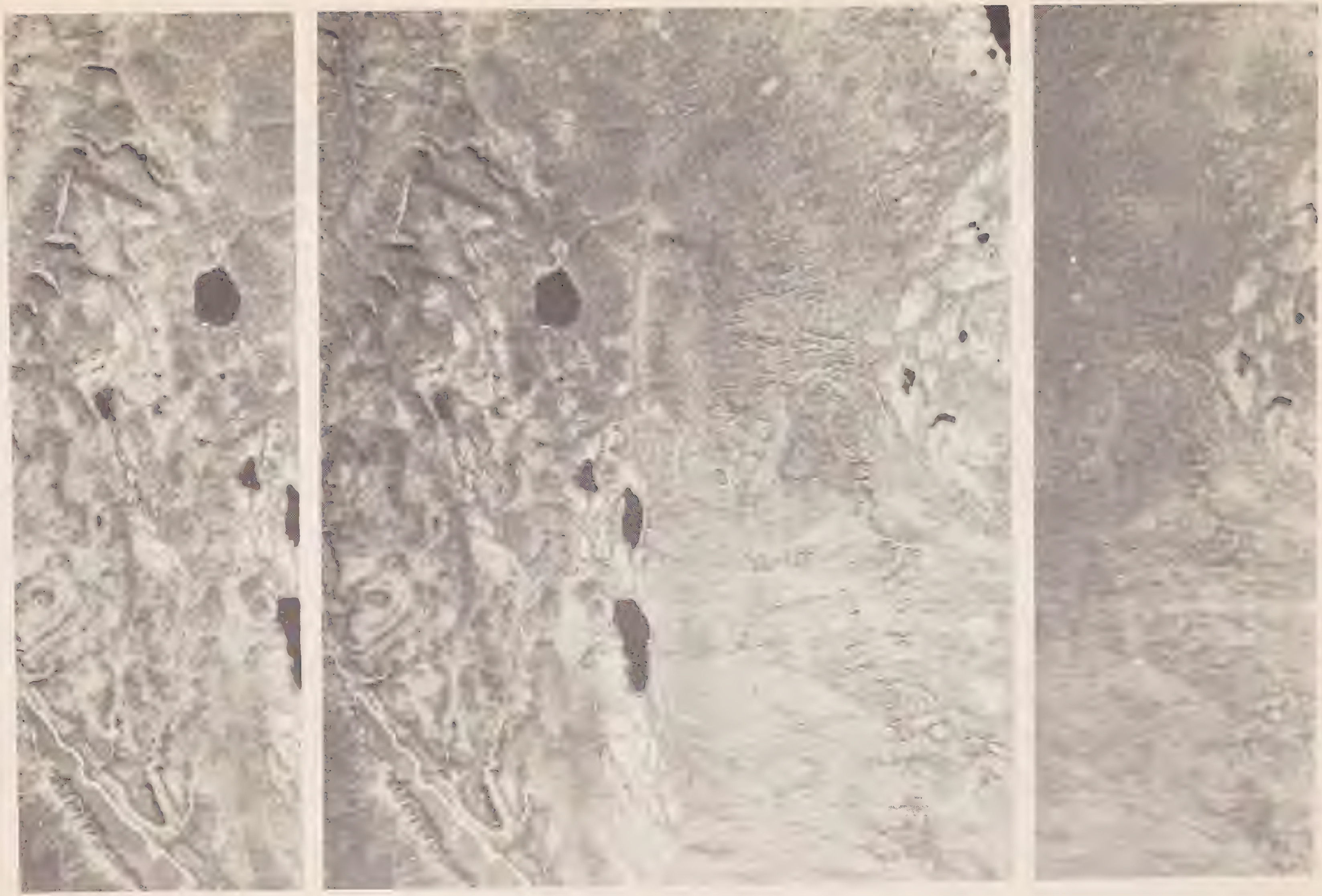


Fig. 14. Stereogram, illustrating principally landscape units 5 and 6. Parts of air-photographs A12252-1,2,3.

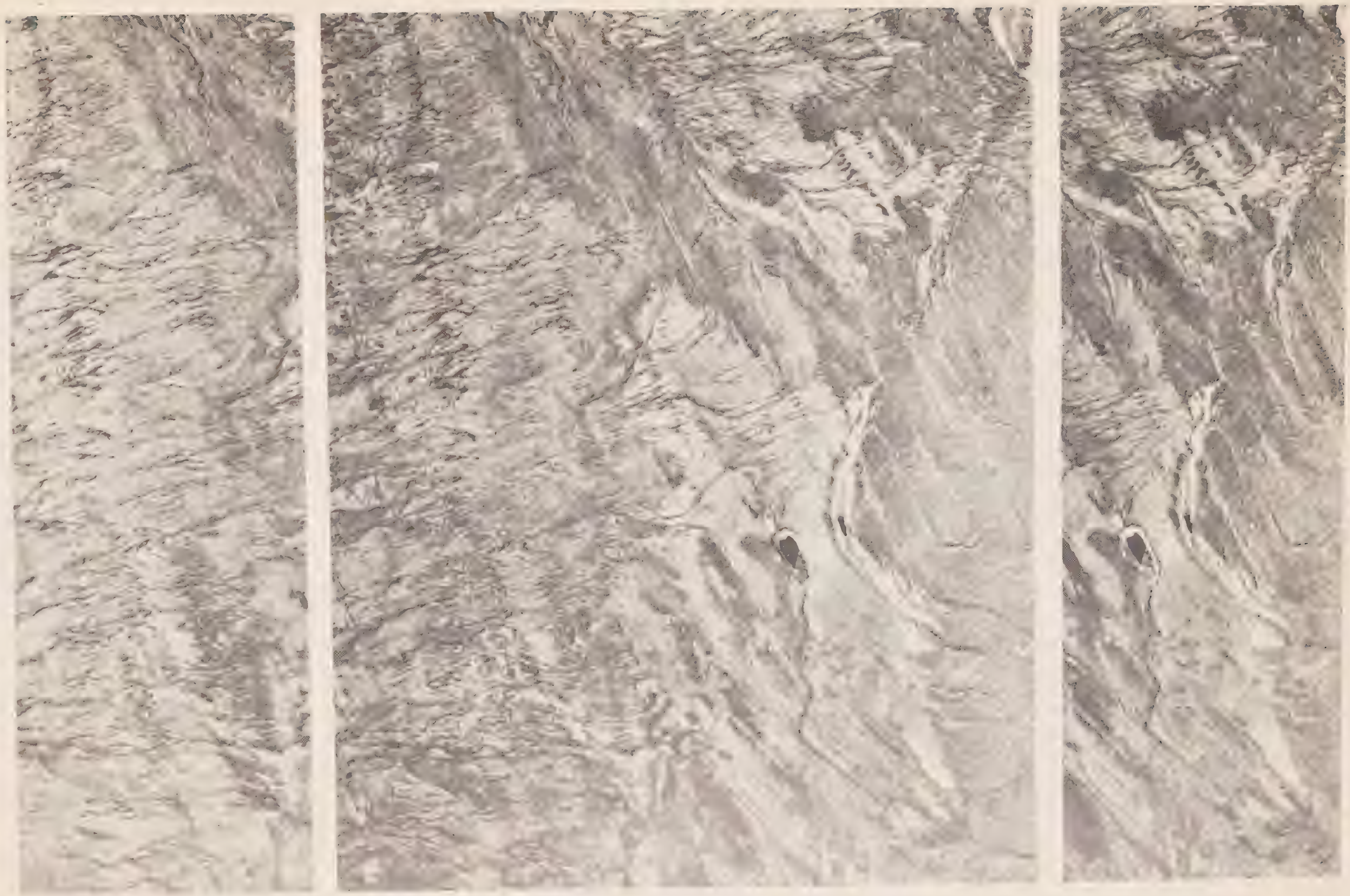
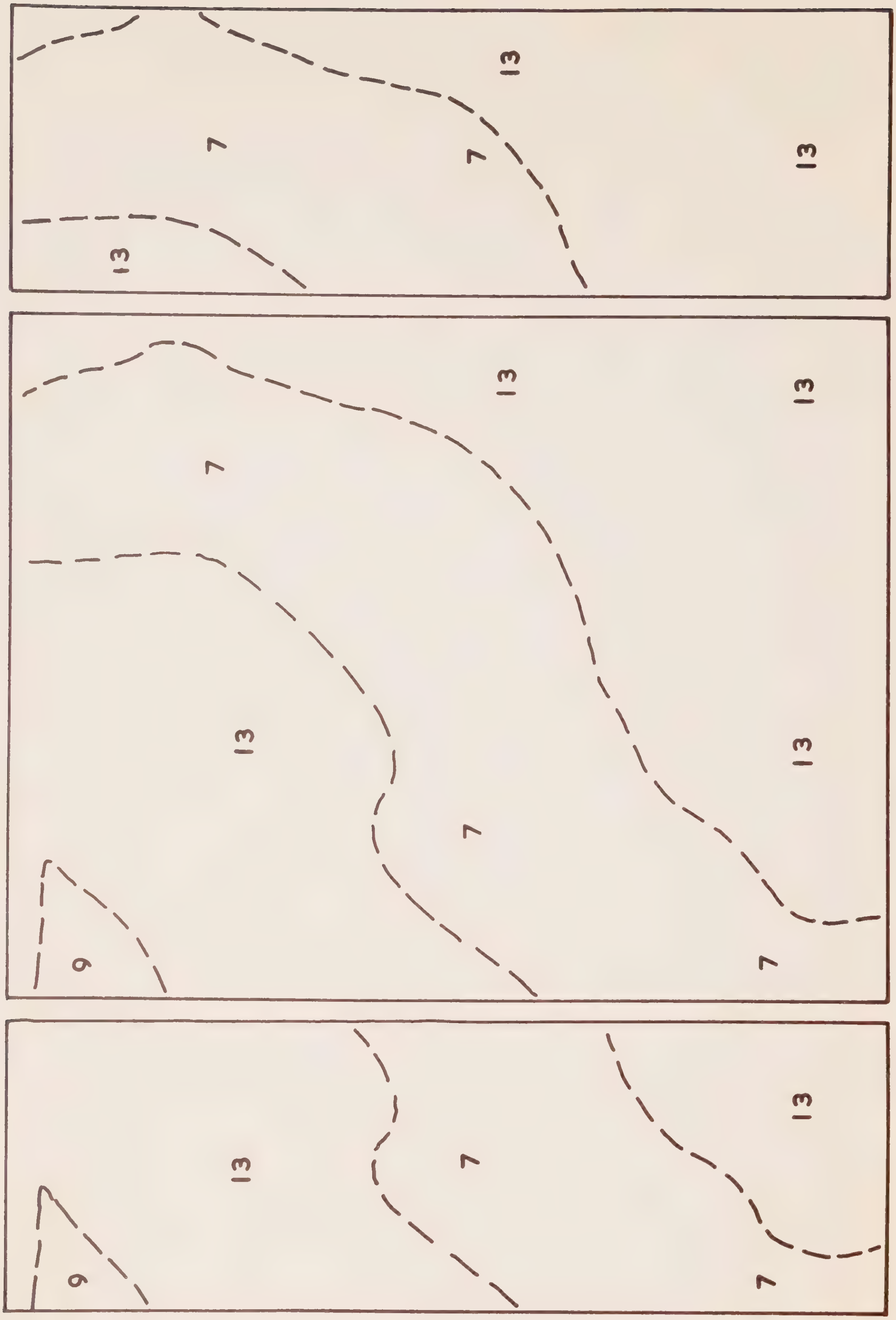


Fig. 15. Stereogram, illustrating principally landscape units 6 and 2. Parts of air-photographs A17430-51,50,49.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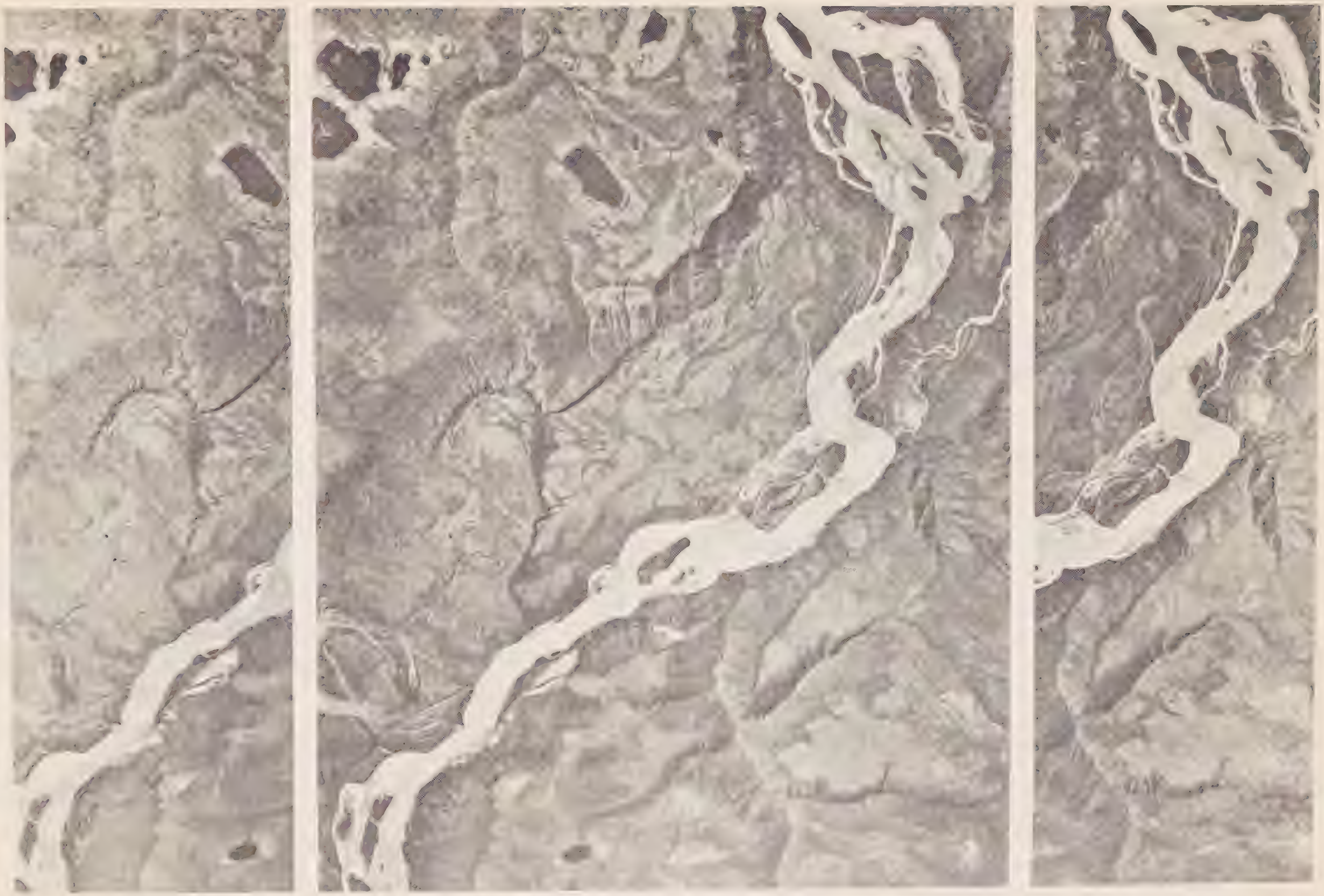


Fig. 14. Stereogram, illustrating principally landscape units 7 and 13. Parts of air-photographs A22474-11,10,9.

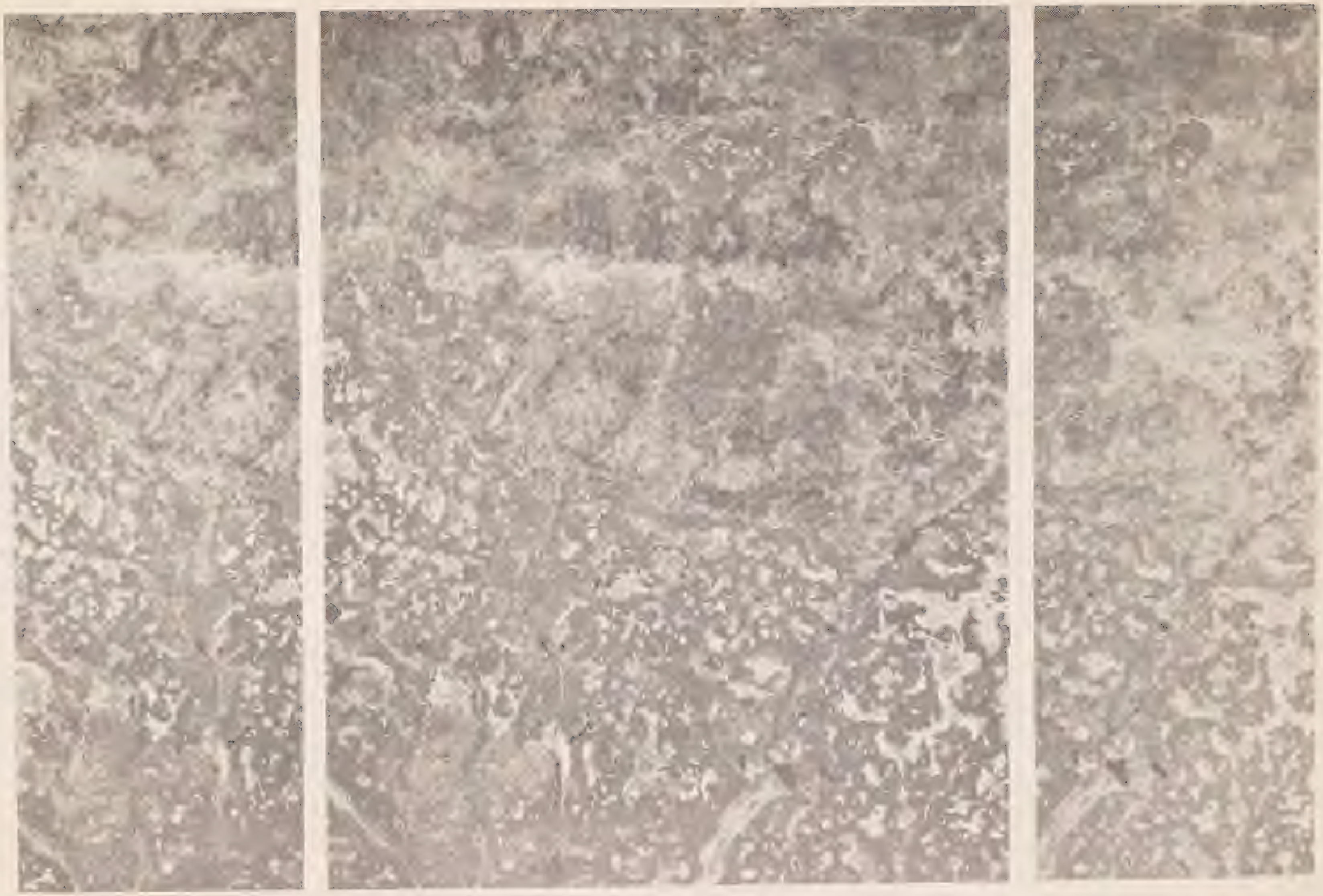
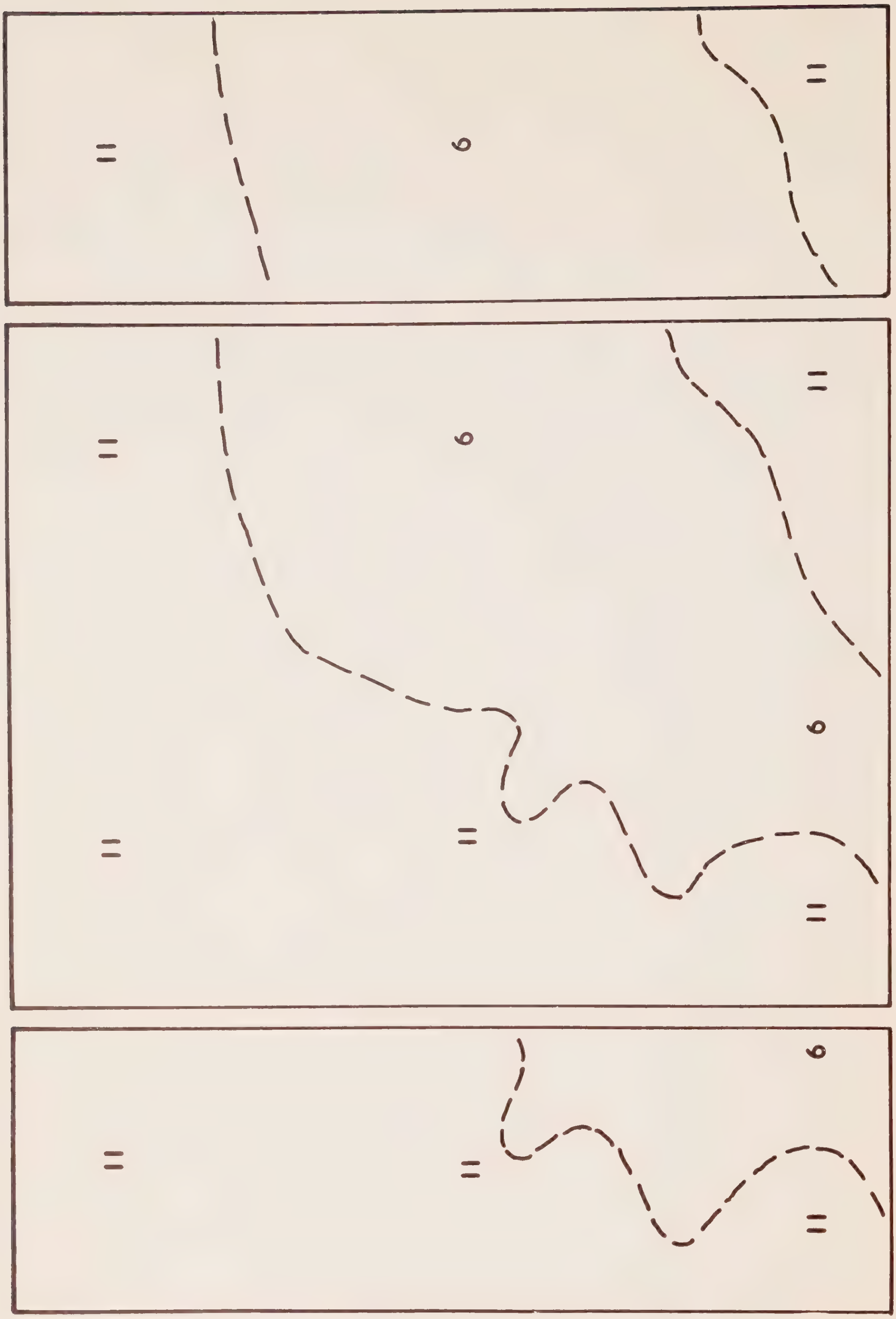


Fig. 17. Stereogram, illustrating principally landscape units 8 and 3. Parts of air-photographs A12578-303,304,305.



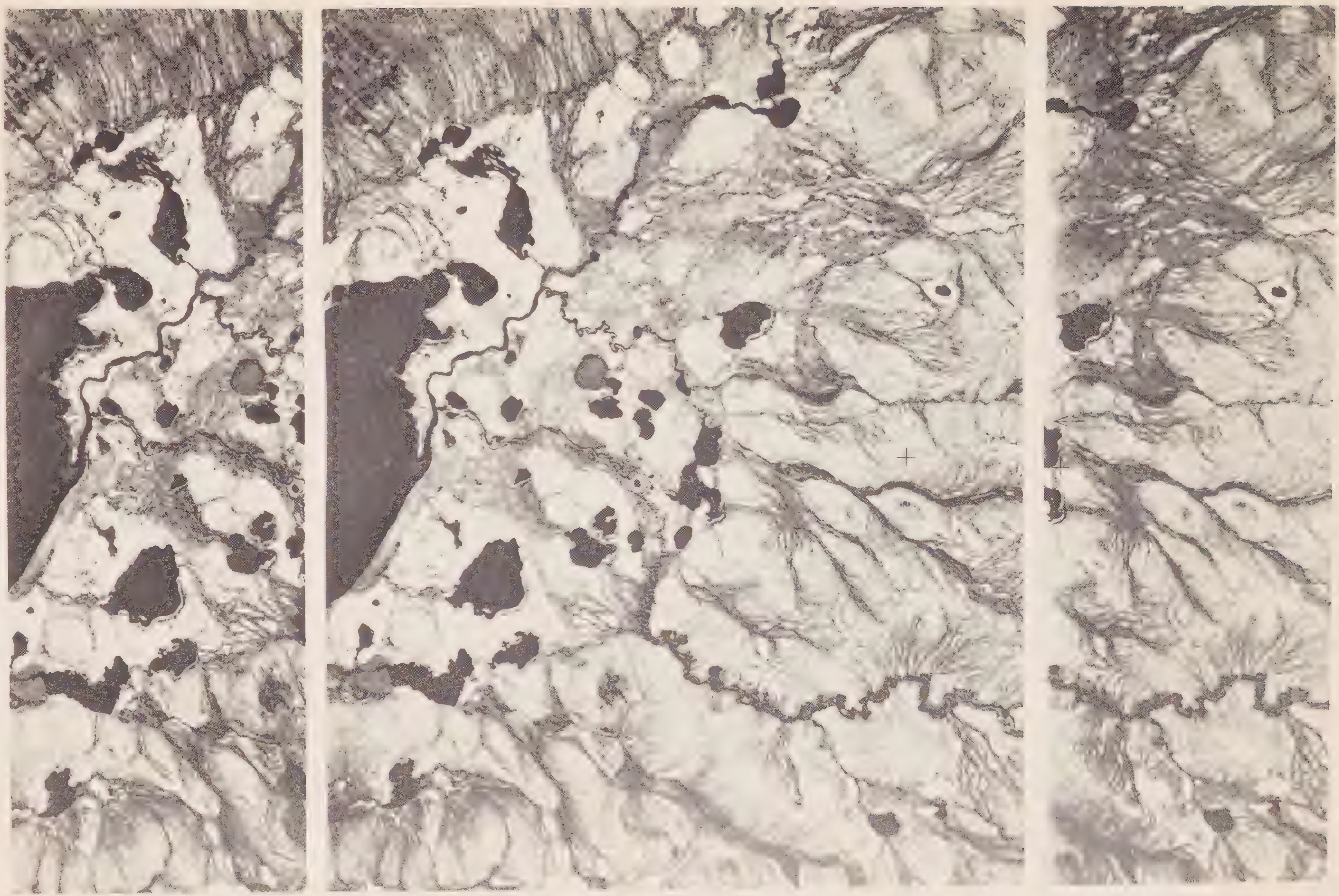
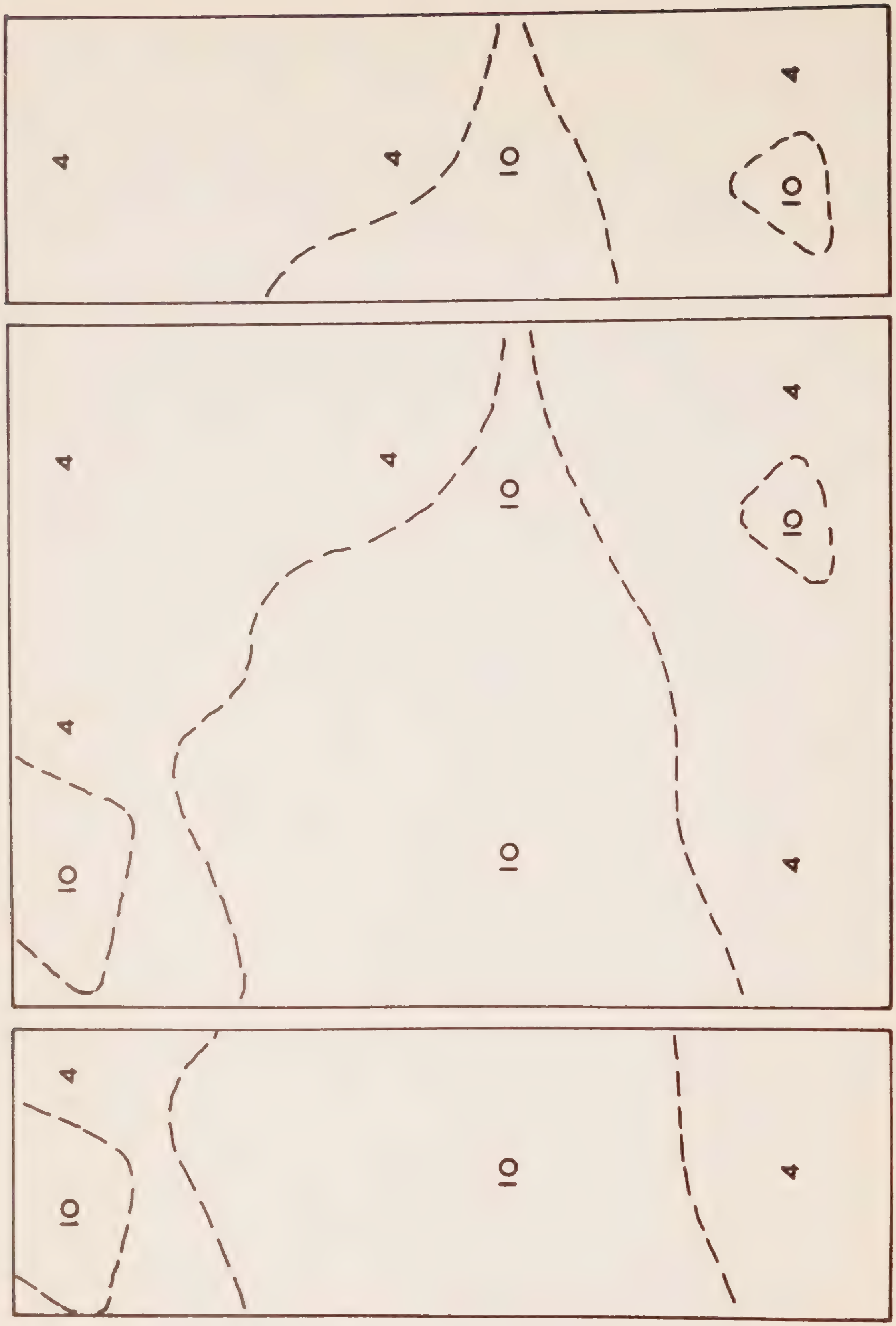


Fig. 18. Stereogram, illustrating principally landscape units 9 and 11. Parts of air-photographs A12586-353.354.355.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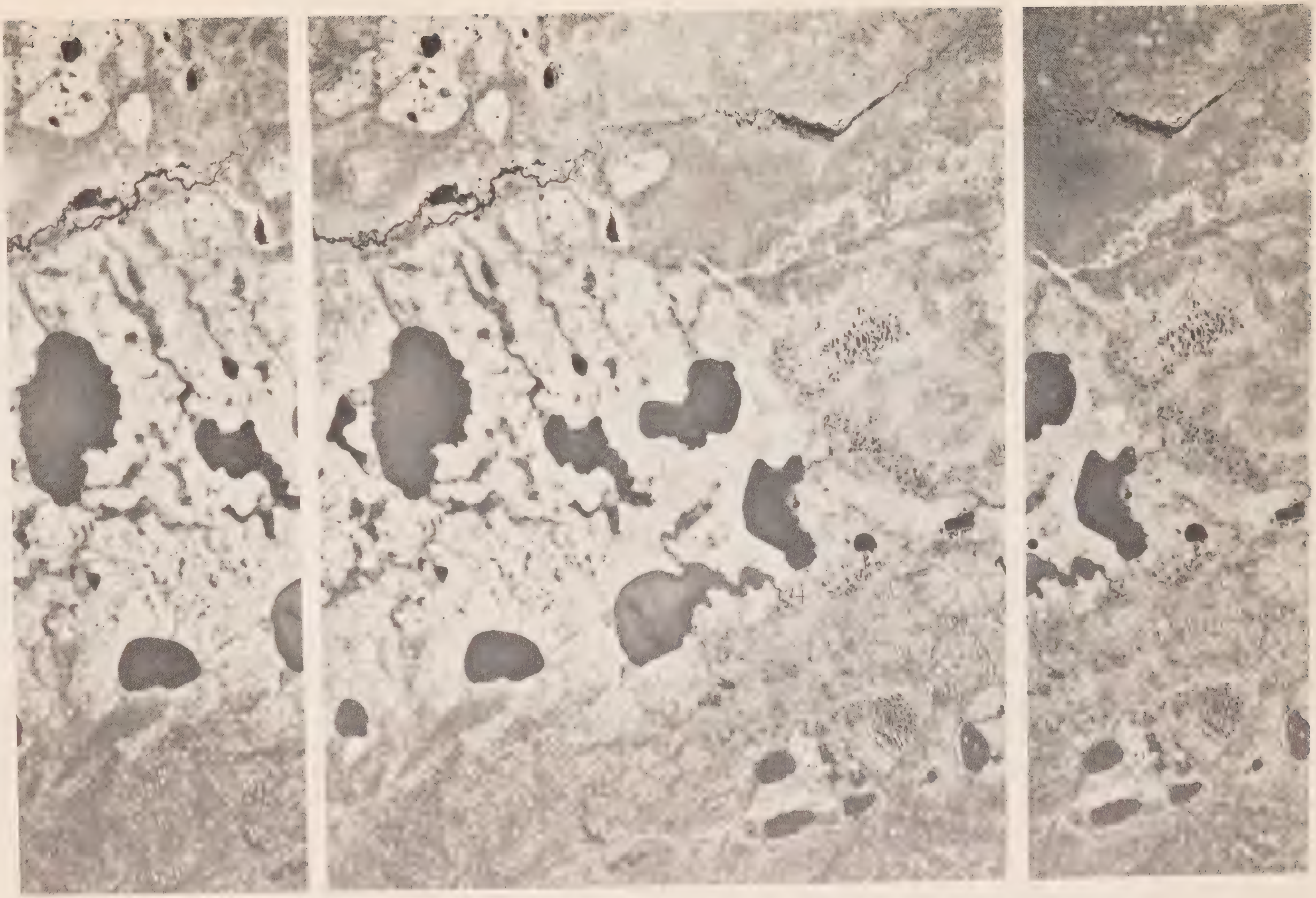
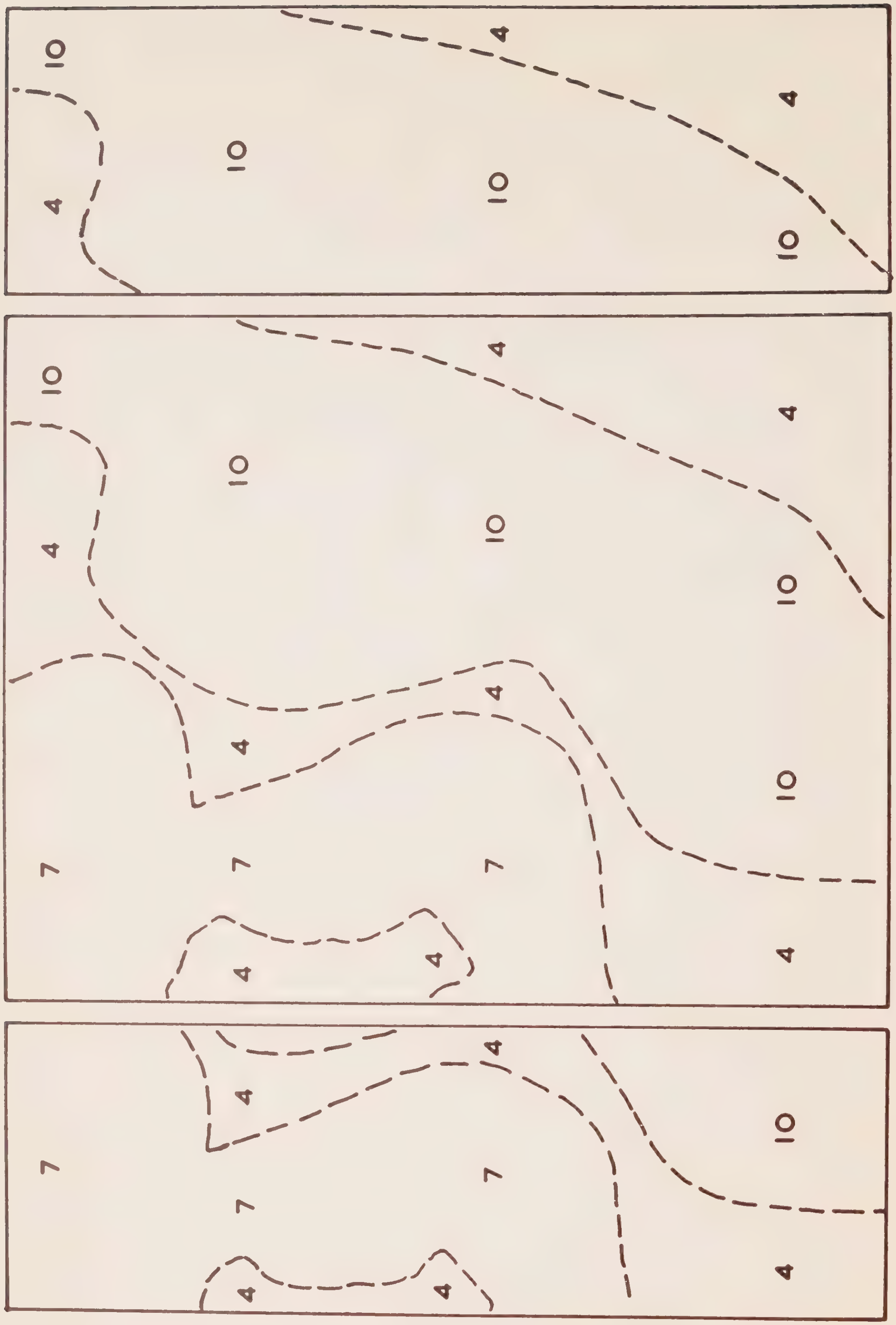


Fig. 19. Stereogram, illustrating principally landscape units 10 and 4. Parts of air-photographs A10992-8,9,10.



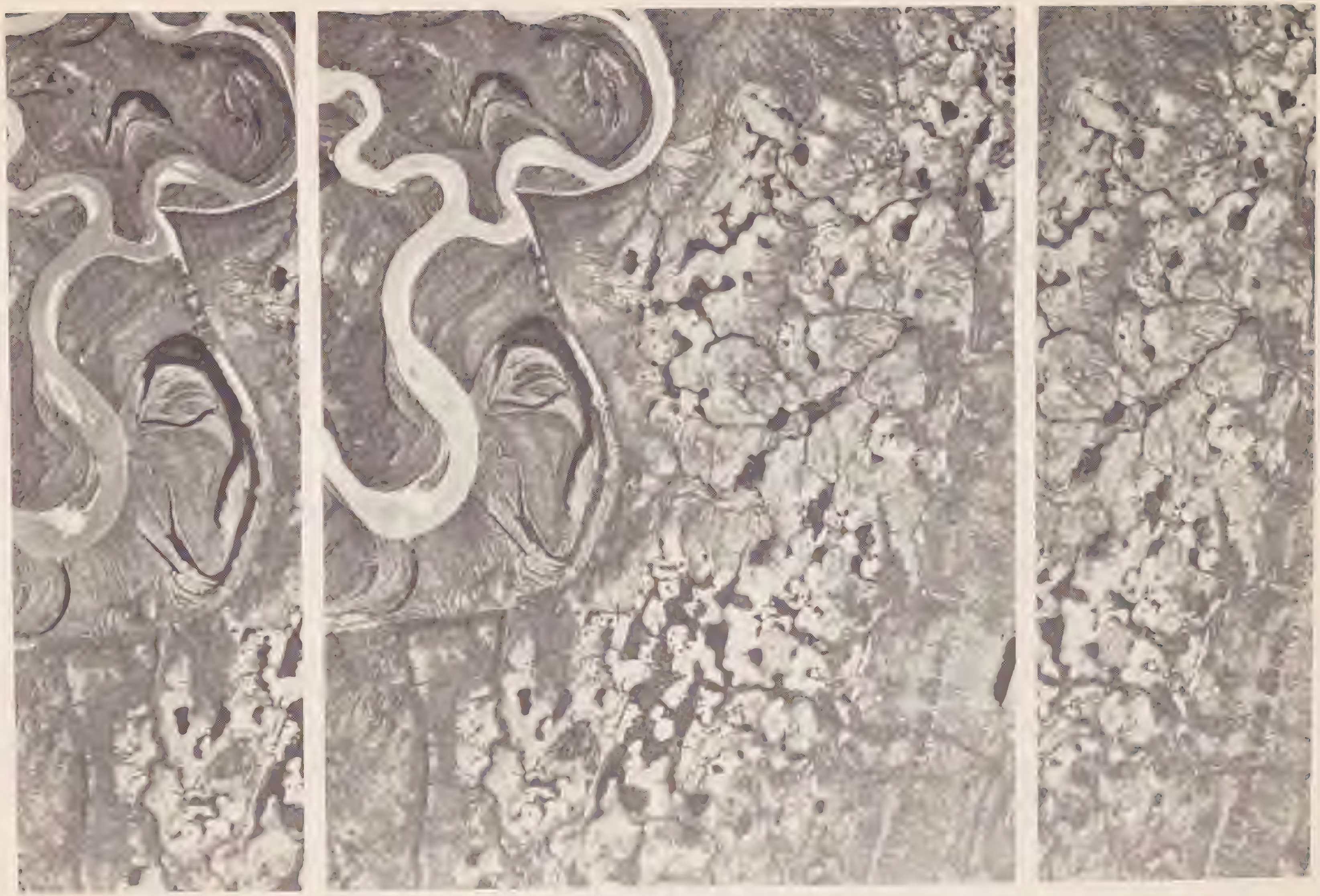
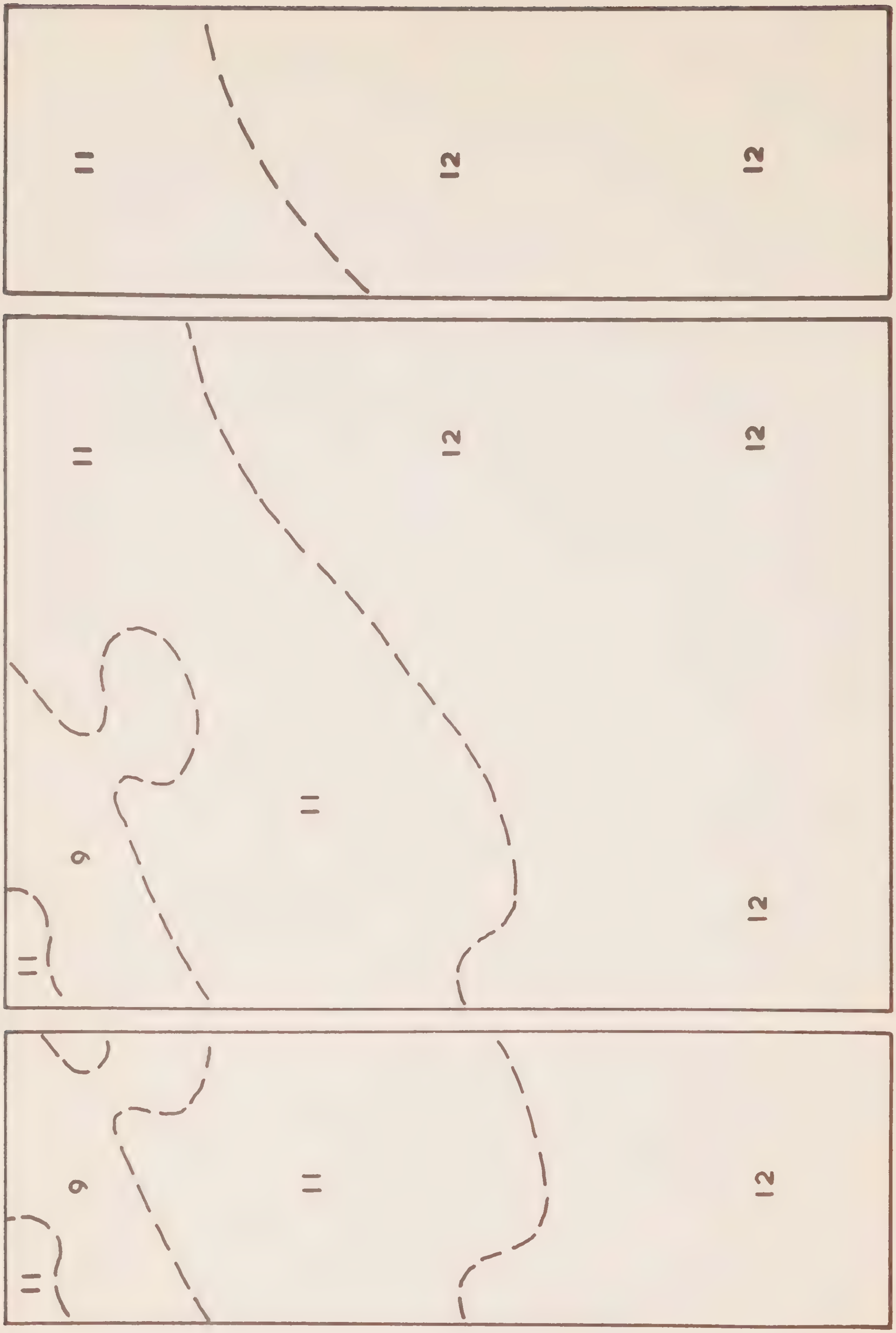


Fig. 20. Stereogram, illustrating principally landscape units 10, 7 and 4. Parts of air-photographs A12579-254,255,256.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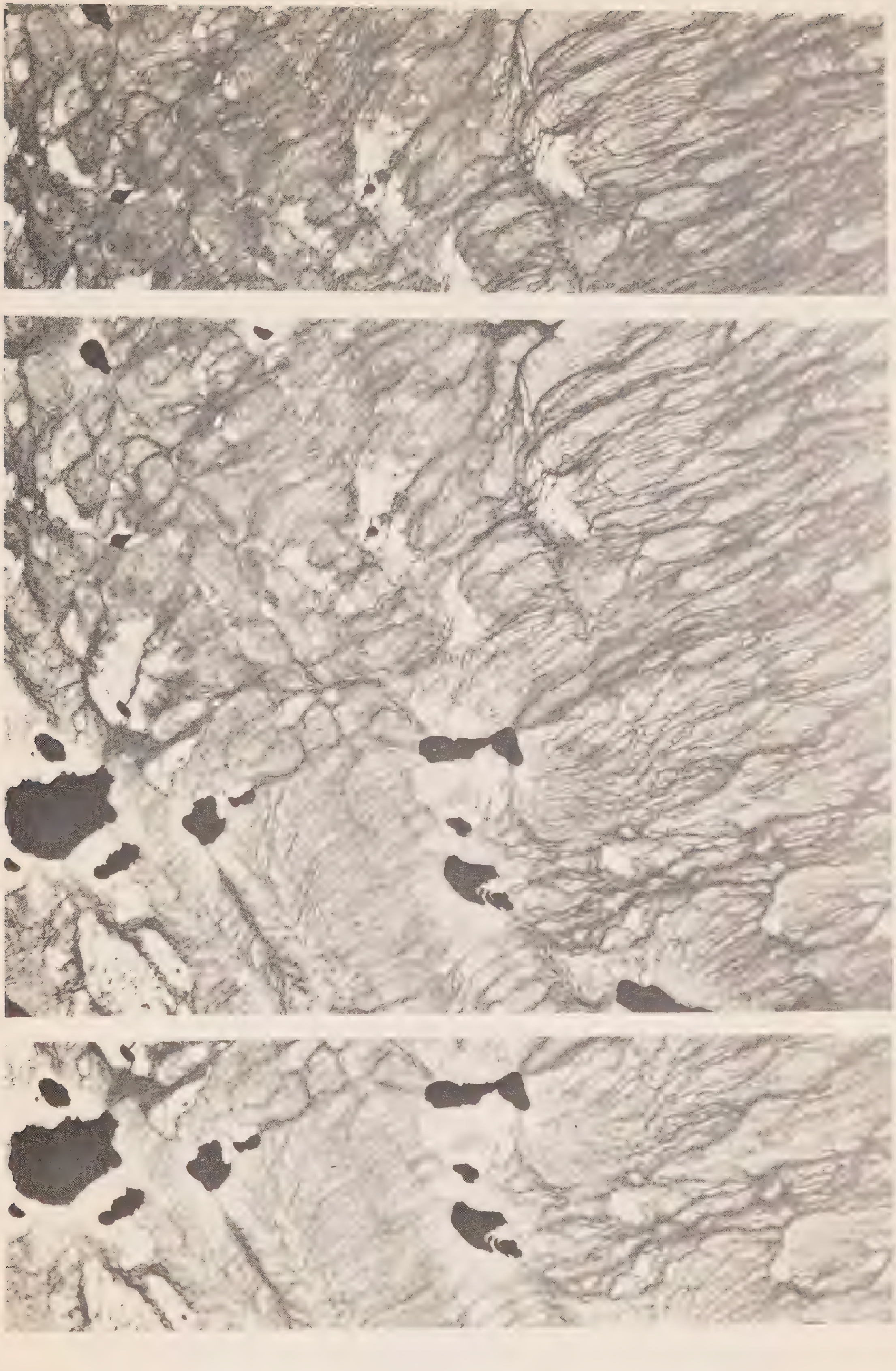
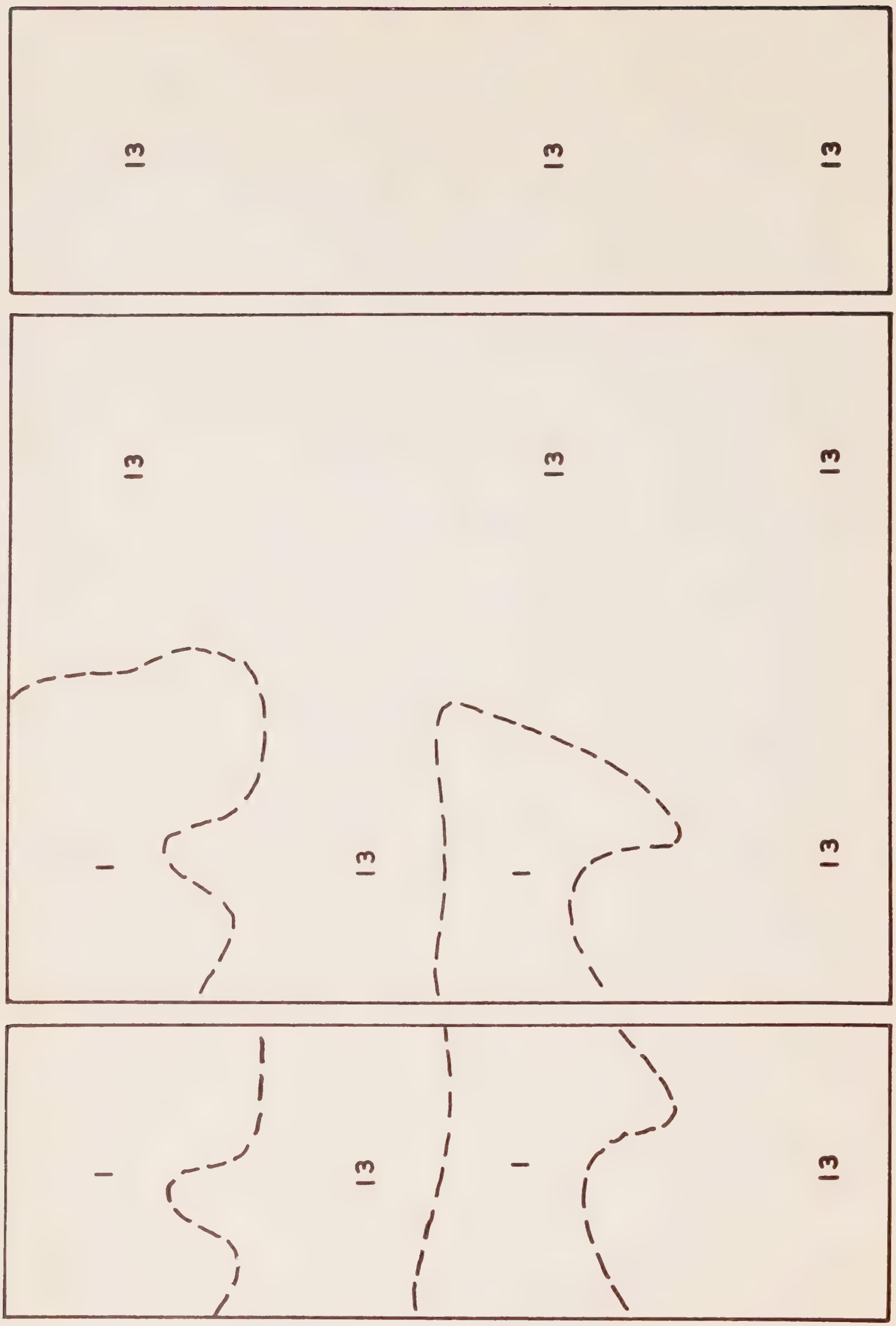


Fig. 21. Stereogram, illustrating principally landscape units 11 and 12. Parts of air-photographs A12609-422,421,420.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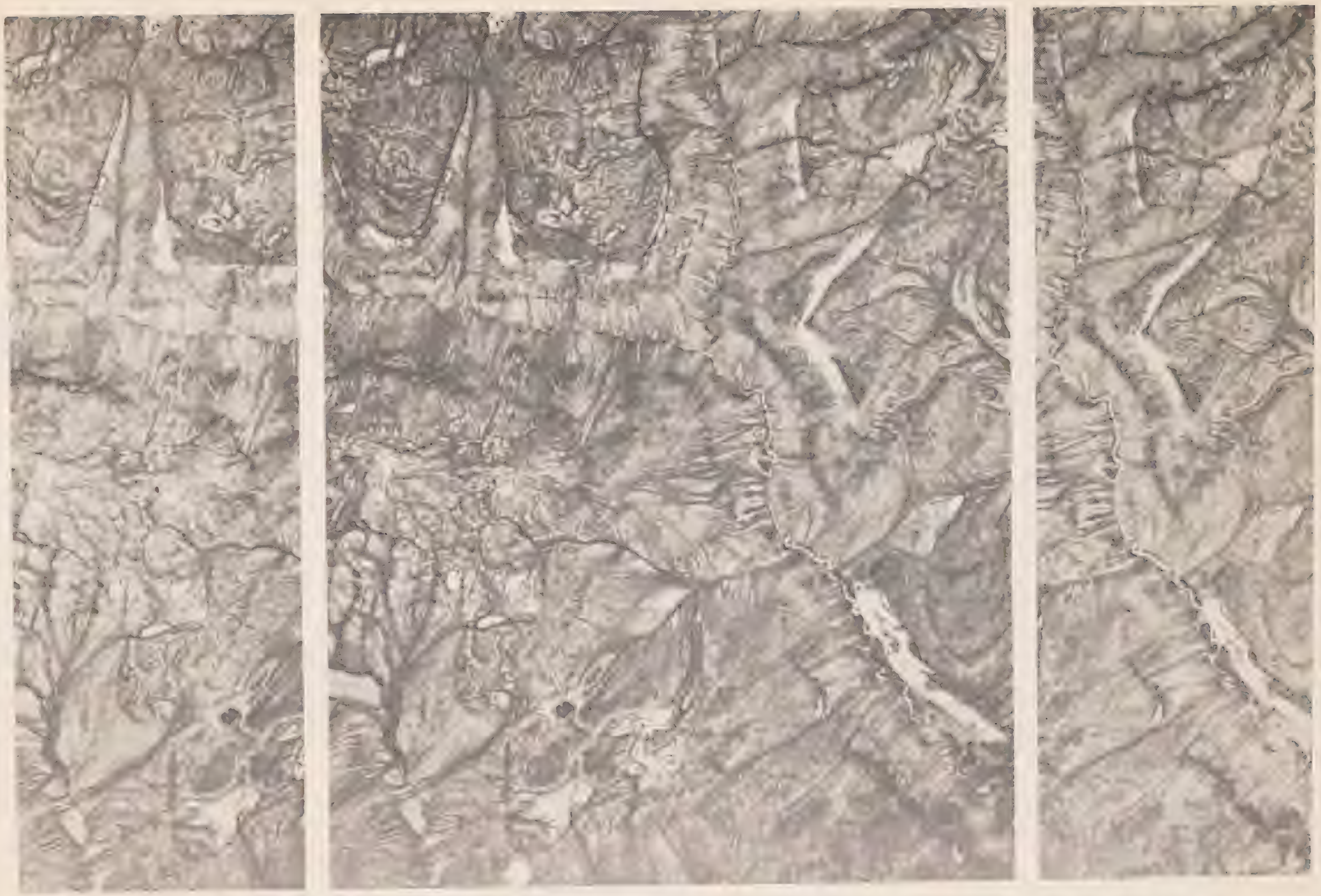

Fig. 22. Stereogram, illustrating principally landscape units I1 and J. Parts of air-photographs 17602-26,27,28.


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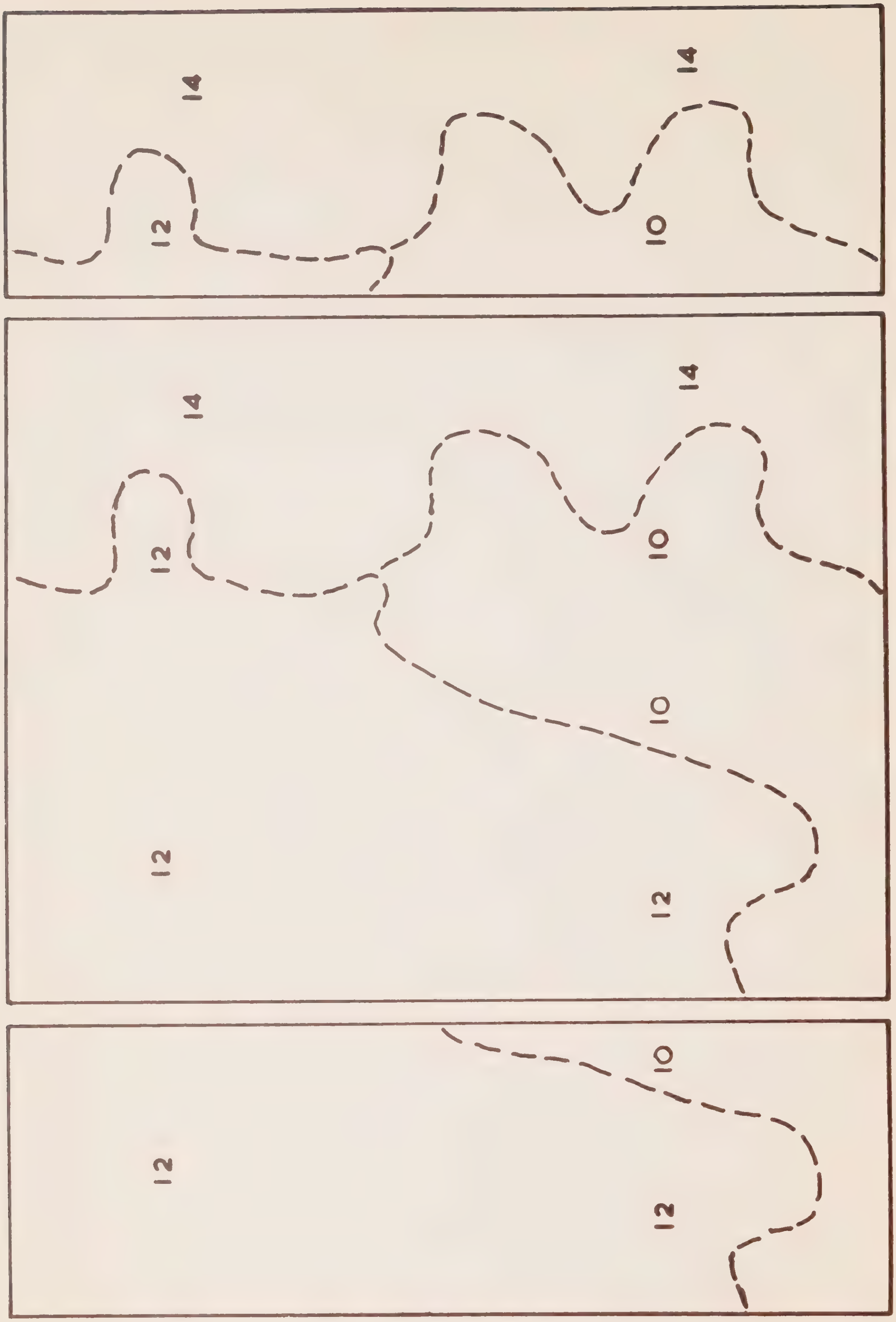
Fig. 23. Stereogram, illustrating principally landscape units 14 and 13. Parts of air-photographs A12148-143,142,141.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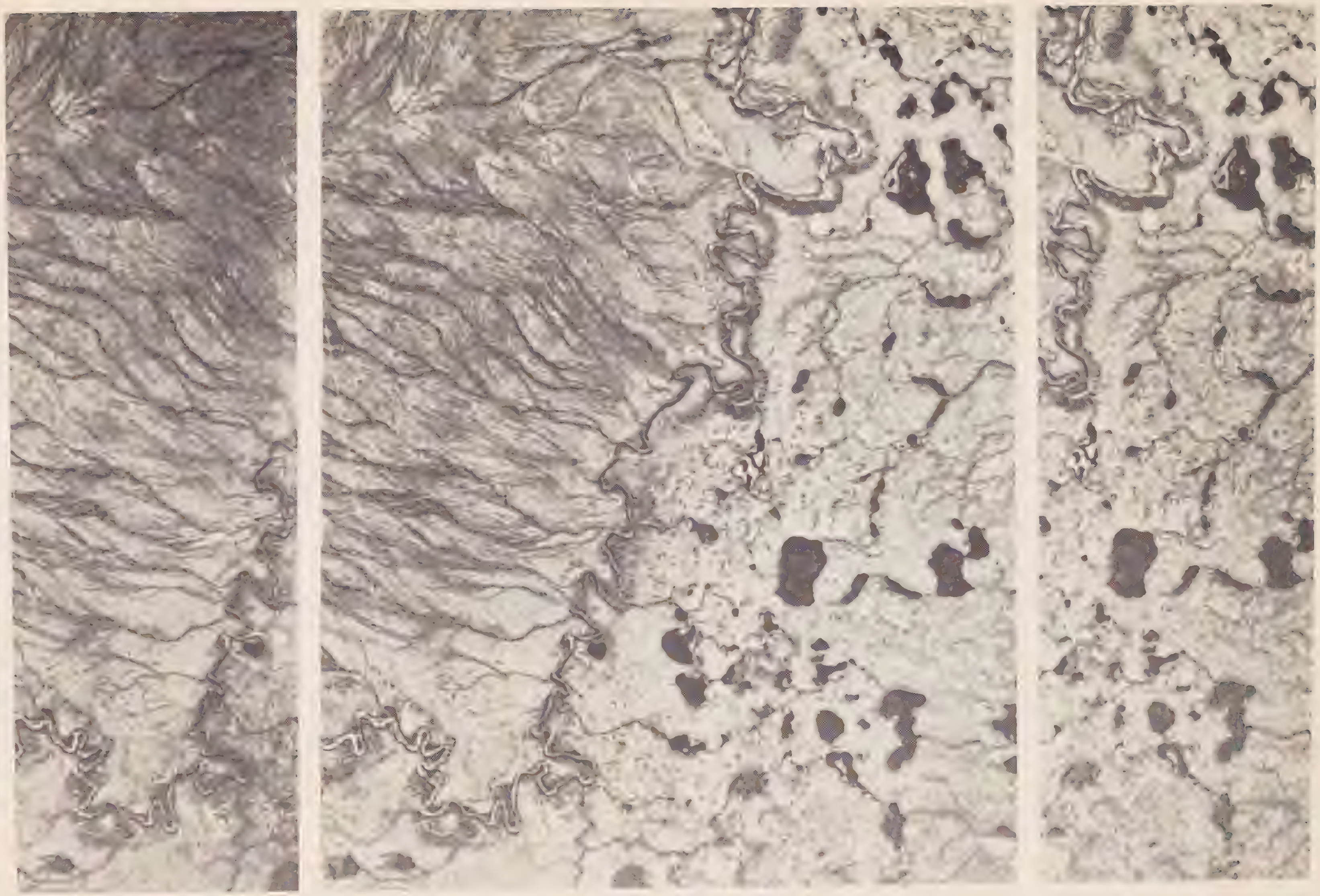

Fig. 24. Stereogram, illustrating principally landscape units 14, 12 and 10. Parts of air-photographs A12697-141,142,143.

13. LIST OF FIGURES AND MAPS.

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*Air Photo Division, Dept. Energy, Mines and Resources. Canadian Govt. Copyright.

Fig. 17. Stereogram, illustrating principally landscape units 8 and 3. Parts of air-photographs A12578-303,304,305. Negative enclosed.

Fig. 18. Stereogram, illustrating principally landscape units 9 and 11. Parts of air-photographs A12586-353,354,355. Negative enclosed.

Fig. 19. Stereogram, illustrating principally landscape units 10 and 4. Parts of air-photographs A10992-8,9,10. Negative enclosed.

Fig. 20. Stereogram, illustrating principally landscape units 10, 7 and 4. Parts of air-photographs A12579-422,421,420. Negative enclosed.

Fig. 21. Stereogram, illustrating principally landscape units 11 and 12. Parts of air-photographs A12609-422,421,420. Negative enclosed.

Fig. 22. Stereogram, illustrating principally landscape units 13 and 1. Parts of air-photographs A12602-26,27,28. Negative enclosed.

Fig. 23. Stereogram, illustrating principally landscape units 14 and 13. Parts of air-photographs A12148-143,142,141. Negative enclosed.

Fig. 24. Stereogram, illustrating principally landscape units 14, 12 and 10. Parts of air-photographs A12697-141,142,143. Negative enclosed.

Map, scale about 1:600,000; terrain susceptibility to damage for the study-area. Reverse-image, vellum positive in attached cylinder.

Map, scale about 1:250,000; landscape survey for the study-area between latitudes 60° and 62°N. Reverse-image, vellum positive in attached cylinder.

Map, scale about 1:250,000; landscape survey for the study-area between latitudes 60° and 64°N. Reverse-image, vellum positive in attached cylinder.

Map, scale about 1:250,000; landscape survey for the study-area between latitudes 64° and 66°N. Reverse-image, vellum positive in attached cylinder.

Figure 5. Selected soil profiles, illustrating decreasingly podzolized soils (from top-left to top-right), to increasingly cryoturbated soils (bottom).

LANDSCAPE SURVEY AND TERRAIN SUSCEPTIBILITY TO DAMAGE FOR THE SOUTHERN AND CENTRAL MACKENZIE RIVER VALLEY

WITH SPECIAL REFERENCE TO THE DEPTH OF THE ACTIVE LAYER, SLOPE AND TEXTURE

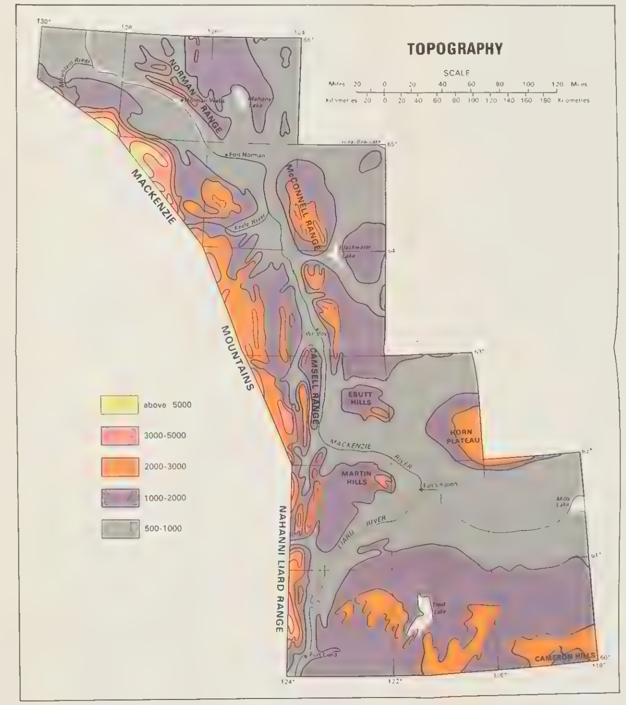
SCALE
1 inch to 10 miles
Miles 10 0 10 20 30 40 50 Miles
Kilometres 10 0 10 20 30 40 50 60 70 Kilometres

Landscape Survey by C. B. Crampton. Maps compiled by C. B. Crampton and M. R. Ross, Canadian Forestry Service, Department of the Environment, for the Environmental—Social Program Northern Pipelines, Task Force on Northern Oil Development, Government of Canada

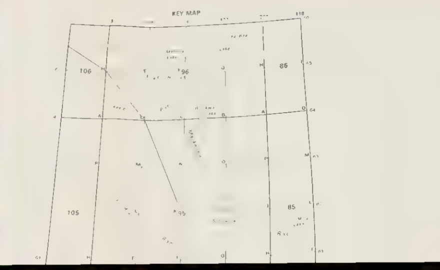
Cartography by the Soil Research Institute, Research Branch, Canada Department of Agriculture, 1973.

EXAMPLES OF DAMAGE

TOPOGRAPHY



KEY MAP



*GROUPING OF SIMILAR LANDSCAPE UNITS

GROUP	LAND SYSTEM NO	GENERAL CHARACTER
LINEAR-PATTERNED SLOPES	14	Hilly moraine and finely lineated slopes with near-surface permafrost.
	13	Rocky plateaus, and finely lineated slopes with near-surface permafrost.
	12	Gentle, coarsely lineated slopes with near surface permafrost.
	11	Moderate, finely lineated slopes with near-surface permafrost.
	6	Steep, lineated slopes without near-surface permafrost
TERRAZOID-PATTERNED PEATY LANDS	10	Hummocky peat plateaus with lichen and near-surface permafrost, and scattered depressions containing summer pools.
	9	Hummocky, peaty mineral soils with near-surface permafrost.
	8	Peat plateaus with labrador tea, locally with near-surface permafrost, and scattered depressions containing summer pools.

LEGEND

The first digit of each full unit symbol gives the Land Region or climatic zone; the second digit the Land District or surficial geology, and these are shown on the map in large numerals. The small numeral indicates the Land System or landscape unit, in most cases this information is shown separately on the map.

Land region — 43 — Land district
4 — Land system

Land region
Land district
Land system

All major areas have been identified in terms of the dominant landscape unit number. The order of landscape units in the legend (1-14) is generally that of susceptibility to damage, though local conditions can change the relative position. Hence, the landscape units have been assigned to four groups for susceptibility to damage from careless traffic. A broad regional appraisal can be made by viewing only the distribution of these four groups. A more detailed assessment can be made by examining the distribution of individual landscape units, and for this purpose a brief description of each unit is given in the table below the legend. The legend gives the general tree height and typical ground vegetation associated with the different land systems

NARRATIVE

The area shows great variation from south to north. On sites with freer drainage in the south soil profiles show chemical weathering, whereas in the north physical weathering is dominant. Maximum podzolization occurs in Land Region 6, and maximum cryoturbation in Land Region 1, in the alpine tundra on mountain plateau tops in the northwest. The more freely drained terrace soils of Land Region 2 are also generally frozen. They occur in the northwest, where the Mackenzie Mountains impinge on the area, and in an outlying site on high plateau land northeast of Wrigley and east of the Mackenzie River. In Land Region 3 the summer permafrost table is near the land surface, except in mineral soils. Lands of this region occur on mountain plateaus on the western border of the area, and east of the Mackenzie River on the Norman and McConnell ranges, the Ebutt Hills and Horn Plateau. There are outlying sites on the top and northern slopes of the Martin Hills, and as far south as the cool, northeastern slopes overlooking Trout Lake

The summer permafrost table of Land Region 4 is moderately near the surface of seasonally waterlogged lands. This region lies in the lowlands on both sides of the Mackenzie River north of Wrigley, along the eastern border of the area southward to the northern side of Horn Plateau and in an outlying area of cold depressed land south of Horn Plateau. Great Bear and Great Slave lakes, near the eastern border of the area, have created a local climate that produces isolated areas of cooler land (Land Region 3) close to the lakes. In Land Region 5 the summer permafrost table is near the surface only in isolated sites, and large areas are seasonally waterlogged.

Unfrozen sites with freer drainage are also important for transportation. These are usually treed, and in the south support the best stands of white spruce, jack pine, or trembling aspen (especially after fire) in the area (Landscape Unit 2). Most lands of this type border the rivers, but bank-slumping may make sites very close to rivers hazardous for transportation lines. They also occur on slopes of morainal or glaciofluvial material and ridges of various kinds. The mineral soils may be frozen (Landscape Unit 7), especially on terraces in Land Regions 1 and 2, or they may be shallow over bedrock (Landscape Unit 1)

Slopes usually have a lineated drainage pattern and are the land type most likely to erode. The problem of erosion is more severe in the north, where the permafrost table occurs near the surface of slopes (Landscape Unit 11), than in the south, where it generally lies deeper (Landscape Unit 6). On gentle slopes where the organic layer is thick (Landscape Unit 12) and the permafrost table is close to the lichenous surface of the slopes, erosion may be severe if the land is badly handled. Slopes on hilly moraine in the north (Landscape Unit 14) or on mountains (Landscape Unit 13) can be equally hazardous

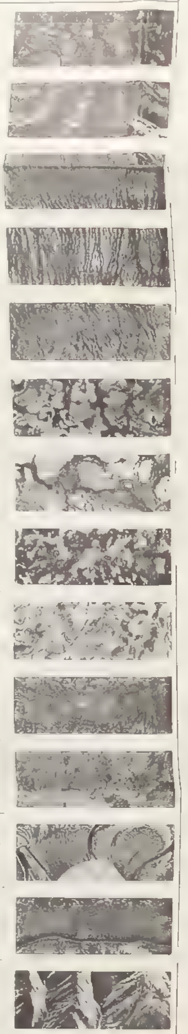
LANDSCAPE

The landscape survey is based on air-photo interpretation, checked by ground observations. Patterns of landforms (drainage) plus vegetation have been delineated that can be identified on air photographs and are indicative of permafrost characteristics. These patterns can be used in mapping lands outside the original area by air-photo interpretation alone, which increases the value

thermal subsidence

*GROUPING OF SIMILAR LANDSCAPE UNITS

GROUP	LAND SYSTEM NO.	GENERAL CHARACTER
LINEAR-PATTERNED SLOPES	14	Hilly moraine and finely lineated slopes with near-surface permafrost
	13	Rocky plateaus, and finely lineated slopes with near-surface permafrost
	12	Gentle, coarsely lineated slopes with near surface permafrost.
	11	Moderate, finely lineated slopes with near-surface permafrost
	6	Steep, lineated slopes without near-surface permafrost
TERRAZOID-PATTERNED PEATY LANDS	10	Hummocky peat plateaus with lichen and near-surface permafrost, and scattered depressions containing summer pools.
	9	Hummocky, peaty mineral soils with near-surface permafrost.
	8	Peat plateaus with labrador tea, locally with near-surface permafrost, and scattered depressions containing summer pools.
SEASONALLY WATERLOGGED LANDS	5	Drumlinoid terrain and intervening seasonally waterlogged lands, locally with near-surface permafrost
	4	Seasonally waterlogged lands with near-surface permafrost.
	3	Seasonally waterlogged lands without near-surface permafrost.
MINERAL SOILS AND ROCK OUTCROPS	7	Freer-drained mineral soils with near-surface permafrost.
	2	Freer-drained mineral soils without near-surface permafrost.
	1	Mountain rock outcrops and screes.



Stereograms in text; photo-miniatures for quick correlation.

LEGEND

The first digit of each full unit symbol gives the Land Region or climatic zone, the second digit the Land District or surficial geology and these are shown on the map in large numerals. The small numeral indicates the Land System or landscape unit, in most cases this information is shown separately on the map

Land region — 43 — Land district
4
Land system

All major areas have been identified in terms of the dominant landscape unit number. The order of landscape units in the legend (1-14) is generally that of susceptibility to damage though local conditions can change the relative position. Hence the landscape units have been assigned to four groups for susceptibility to damage from careless traffic. A broad regional appraisal can be made by viewing only the distribution of these four groups. A more detailed assessment can be made by examining the distribution of individual landscape units, and for this purpose a brief description of each unit is given in the table below the legend. The legend gives the general tree height and typical ground vegetation associated with the different land systems.

Land region
Land district
Land system

NARRATIVE

The area shows great variation from south to north. On sites with freer drainage in the south soil profiles show chemical weathering, whereas in the north physical weathering is dominant. Maximum podzolization occurs in Land Region 6, and maximum cryoturbation in Land Region 1, in the alpine tundra on mountain plateau tops in the northwest. The more freely drained terrace soils of Land Region 2 are also generally frozen. They occur in the northwest where the Mackenzie Mountains impinge on the area, and in an outlying site on high plateau land northeast of Wrigley and east of the Mackenzie River. In Land Region 3 the summer permafrost table is near the land surface, except in mineral soils. Lands of this region occur on mountain plateaus on the western border of the area, and east of the Mackenzie River on the Norman and McConnell ranges, the Ebutt Hills and Horn Plateau. There are outlying sites on the top and northern slopes of the Martin Hills, and as far south as the cool, northeastern slopes overlooking Trout Lake.

The summer permafrost table of Land Region 4 is moderately near the surface of seasonally waterlogged lands. This region lies in the lowlands on both sides of the Mackenzie River north of Wrigley, along the eastern border of the area southward to the northern side of Horn Plateau, and in an outlying area of cold, depressed land south of Horn Plateau. Great Bear and Great Slave lakes, near the eastern border of the area, have created a local climate that produces isolated areas of cooler land (Land Region 3) close to the lakes. In Land Region 5, the summer permafrost table is near the surface only in isolated sites, and large areas are seasonally waterlogged. This region, like Region 4, is located mainly in the south and east, occurring in lowlands on both sides of the Mackenzie and Liard rivers and round Horn Plateau. Land Region 6 is found only in the south.

Silty-clayey morainal deposits (Land District 1) are most widespread in the east and south of the area, away from the rivers. Sandy or gravelly deposits (Land District 2) occur in local sites such as the north side of Cameron Hills. On both sides of the Mackenzie and Liard rivers in the south, broad expanses of silty-clayey lacustrine deposits (Land Deposit 3) are remnants of a single, large, glacially impounded lake. Another impounded lake in the north has also left extensive lacustrine deposits. In local areas the deposits are sandy and gravelly (Land District 4). The lacustrine material of both glacial lakes has been locally re-sorted by wind in postglacial times, to form areas of sand dunes (Land District 5). A thin layer of morainal material over bedrock is common in the mountains (Land District 6).

A belt of seasonally waterlogged lands lies along the Mackenzie River throughout the area, broken only north of Wrigley where mountain slopes approach both sides of the river. It is widest in the southeast (Landscape Unit 3) then narrows until in the north (Landscape Unit 4) it is restricted by mountains west of the river and spreads out on flat lands to the east. In Landscape Unit 4, although the surface is waterlogged the permafrost table is closer to the surface than in Landscape Unit 3. Also, land of Unit 4 is more frequently mingled with areas where the depth to permafrost is so shallow that the surface is dry in summer and supports lichens (Landscape Unit 9). A thick, crisp mat of lichens (Landscape Unit 10) occurs where frozen peat has built up sufficiently for the soils to be classed as organic. In the south these peat plateaus, generally associated with Labrador-tea (Landscape Unit 8), are largest on the plateau lands of Land Region 6. In all parts of the area, peat plateaus are most widespread on morainal or lacustrine deposits (particularly the latter) that are silty or clayey. This makes sandy and gravelly areas important for transportation lines.

Unfrozen sites with freer drainage are also important for transportation. These are usually treed, and in the south support the best stands of white spruce, jack pine, or trembling aspen (especially after fire) in the area (Landscape Unit 2). Most lands of this type border the rivers, but bank-slumping may make sites very close to rivers hazardous for transportation lines. They also occur on slopes of morainal or glaciolluvial material and ridges of various kinds. The mineral soils may be frozen (Landscape Unit 7), especially on terraces in Land Regions 1 and 2, or they may be shallow over bedrock (Landscape Unit 1).

Slopes usually have a lineated drainage pattern and are the land type most likely to erode. The problem of erosion is more severe in the north, where the permafrost table occurs near the surface of slopes (Landscape Unit 11), than in the south, where it generally lies deeper (Landscape Unit 6). On gentle slopes where the organic layer is thick (Landscape Unit 12) and the permafrost table is close to the lichenous surface of the slopes, erosion may be severe if the land is badly handled. Slopes on hilly moraine in the north (Landscape Unit 14) or on mountains (Landscape Unit 13) can be equally hazardous.

LANDSCAPE

The landscape survey is based on air-photo interpretation, checked by ground observations. Patterns of landforms (drainage) plus vegetation have been delineated that can be identified on air photographs and are indicative of permafrost characteristics. These patterns can be used in mapping lands outside the original area by air-photo interpretation alone, which increases the value of the survey and provides a basis for possible extension of the area of interest.

LAND REGIONS

Land Regions are equivalent to climatic zones in several ways. They are characterized by soil types on the sites with freer drainage (terrace and river banks, morainal and glaciofluvial ridges) that range from podzolized soils in the southernmost part, Land Region 6, to cryoturbated soils in the northernmost highest area, Land Region 1. Also, the regions differ in the proportions of seasonally frozen and unfrozen land. Hence, land susceptible to damage from careless traffic becomes progressively more widespread from south to north, lineated slopes are the most easily harmed.

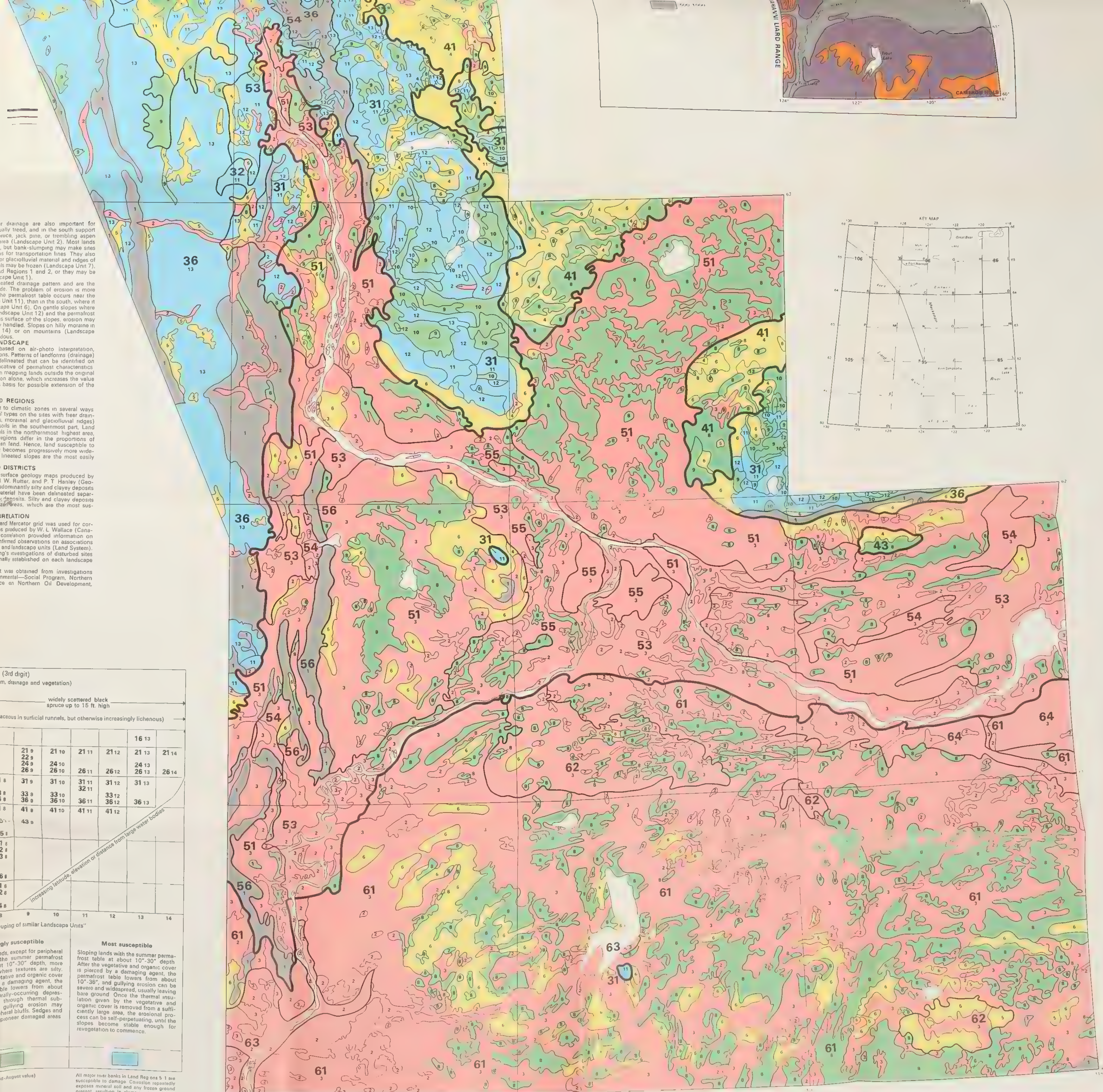
LAND DISTRICTS

Land Districts are based on surface geology maps produced by O. L. Hughes, R. J. Fulton, N. W. Rutter, and P. T. Hanley (Geological Survey of Canada). Predominantly silty and clayey deposits of morainal and lacustrine material have been delineated separately from sandy and gravelly deposits. Silty and clayey deposits form the most extensive frozen areas, which are the most susceptible to damage.

CORRELATION

A count based on the standard Mercator grid was used for correlation with vegetation maps produced by W. L. Wallace (Canadian Forestry Service). This correlation provided information on general tree heights and confirmed observations on associations of general ground vegetation and landscape units (Land System). Correlations with R. M. Strang's investigations of disturbed sites revealed the vegetation normally established on each landscape unit after disturbance.

The data for this report was obtained from investigations carried out under the Environmental—Social Program, Northern Pipelines, of the Task Force on Northern Oil Development, Government of Canada.



LAND REGIONS (1st digit)
(climatic zones)

Characterized by the soils on the most constantly similar sites from Region to Region, the freer-drained mineral soil sites. The profound climatic change from the tundra Mackenzie Mountain Land Region in the NW, to the boreal Trout Lake Land Region in the S. is best illustrated by:

LAND DISTRICTS (2nd digit)
(dominant parent material)

1. silty-clayey morainal
2. sandy-gravelly morainal
3. silty-clayey lacustrine
4. sandy-clayey lacustrine
5. eolian
6. shallow bedrock

LAND SYSTEMS (3rd digit)
*(landscape unit: composite of landform, drainage and vegetation)

— mostly white spruce, up to 75 ft. high — mostly white spruce, up to 50 ft. high — mostly scattered black spruce up to 25 ft. high — widely scattered black spruce up to 15 ft. high →

rock flora; herbaceous-grassy; sedgy-sphagnaceous; sphagnaceous-lichenous — (sphagnaceous in surficial runnels, but otherwise increasingly lichenous) →

Land Regions		Land Districts	1 rock flora	2 herbaceous-grassy	3 sedgy-sphagnaceous	4	5 sphagnaceous-lichenous	6	7	8	9	10	11	12	13	14
Cryoturbation processes dominant, giving vertical layering in the soil profile:	1. MACKENZIE MOUNTAIN "Turbic" regosol	16	16_1						16_7						16_{13}	
	2. CARCAJOU CANYON Cryic regosol	21 22 24 26	21_1 24_1 26_1			21_4	21_5 22_5 24_5 26_5	21_6	21_7 24_7 26_7		21_9 22_9 24_9 26_9	21_{10} 24_{10} 26_{10}	21_{11} 26_{11}	21_{12} 26_{12}	21_{13} 24_{13} 26_{13}	21_{14} 26_{14}
	3. HORN PLATEAU Alpine eutric brunisol	31 32 33 36	31_1 36_1	31_2 32_2 33_2 36_2		31_4 33_4 36_4	31_5 32_5 36_5	31_6 36_6		31_8 33_8 36_8	31_9 33_9 36_9	31_{10} 33_{10} 36_{10}	31_{11} 32_{11} 36_{11}	31_{12} 33_{12} 36_{12}	31_{13} 36_{13}	
	4. NORMAN WELLS Degraded eutric brunisol	41 42 43 44 45	41_1 43_1	41_2 43_2 44_2 45_2		41_4 43_4 44_4 45_4	41_5 42_5 43_5	41_6 43_6		41_8 43_8 45_8	41_9 43_9	41_{10}	41_{11}	41_{12}		
	5. FORT SIMPSON Degraded dystric brunisol	51 52 53 54 55 56	51_1 56_1	51_2 53_2 54_2 56_2	51_3 52_3 53_3 54_3 55_3 56_3		51_5 52_5	51_6 53_6 54_6 56_6		51_8 52_8 53_8 56_8						
Pedological processes dominant, giving horizontal layering in the soil profile.	6. TROUT LAKE "Podzolized" dystric brunisol	61 62 63 64	61_1	61_2 62_2 64_2	61_3 62_3 63_3 64_3		61_5 62_5	61_6 62_6 63_6		61_8 62_8 64_8						

increasing latitude, elevation or distance from large water bodies

*For identification of Land Systems, see "Grouping of similar Landscape Units"

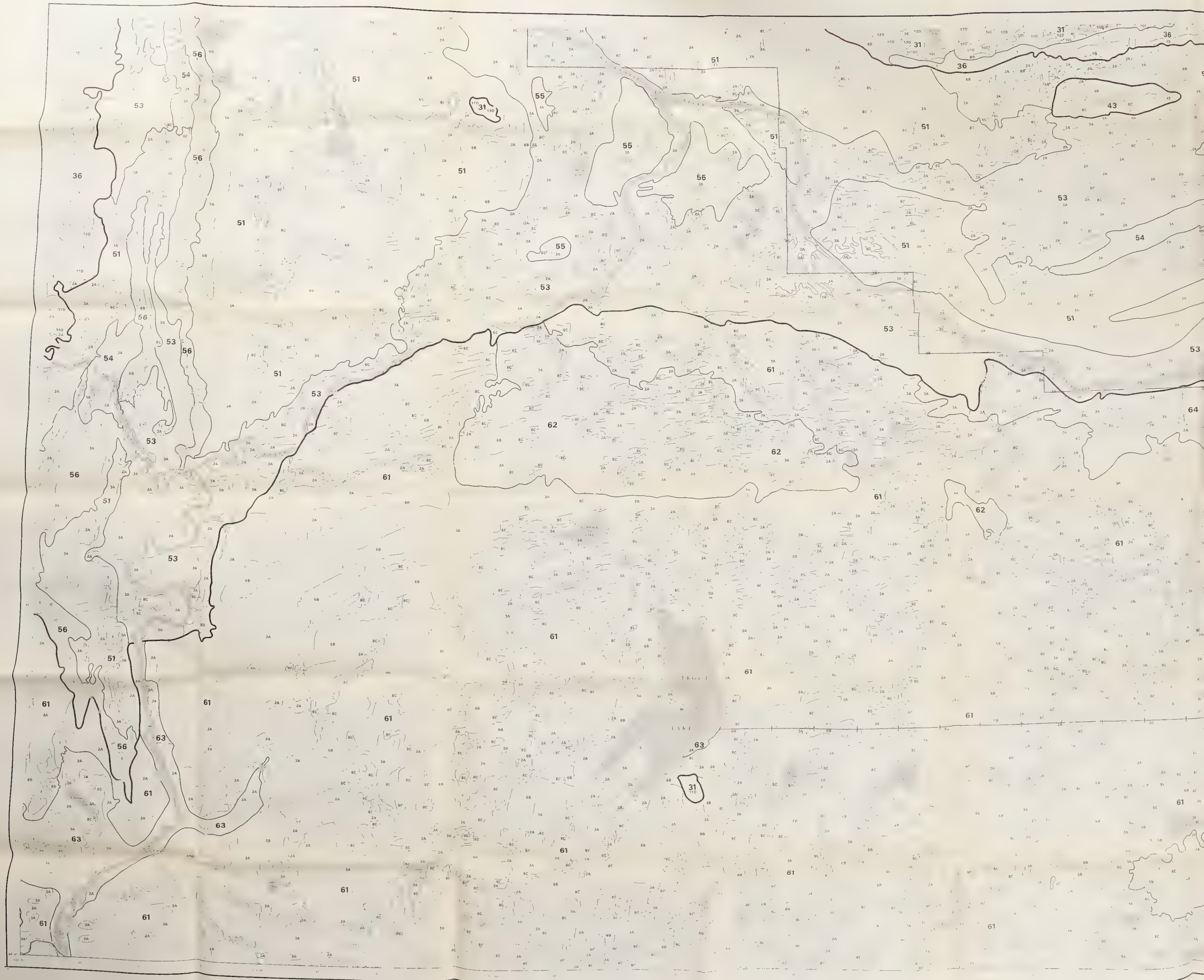
LEGEND FOR LANDSCAPE SURVEY AND DAMAGE SUSCEPTIBILITY MAP

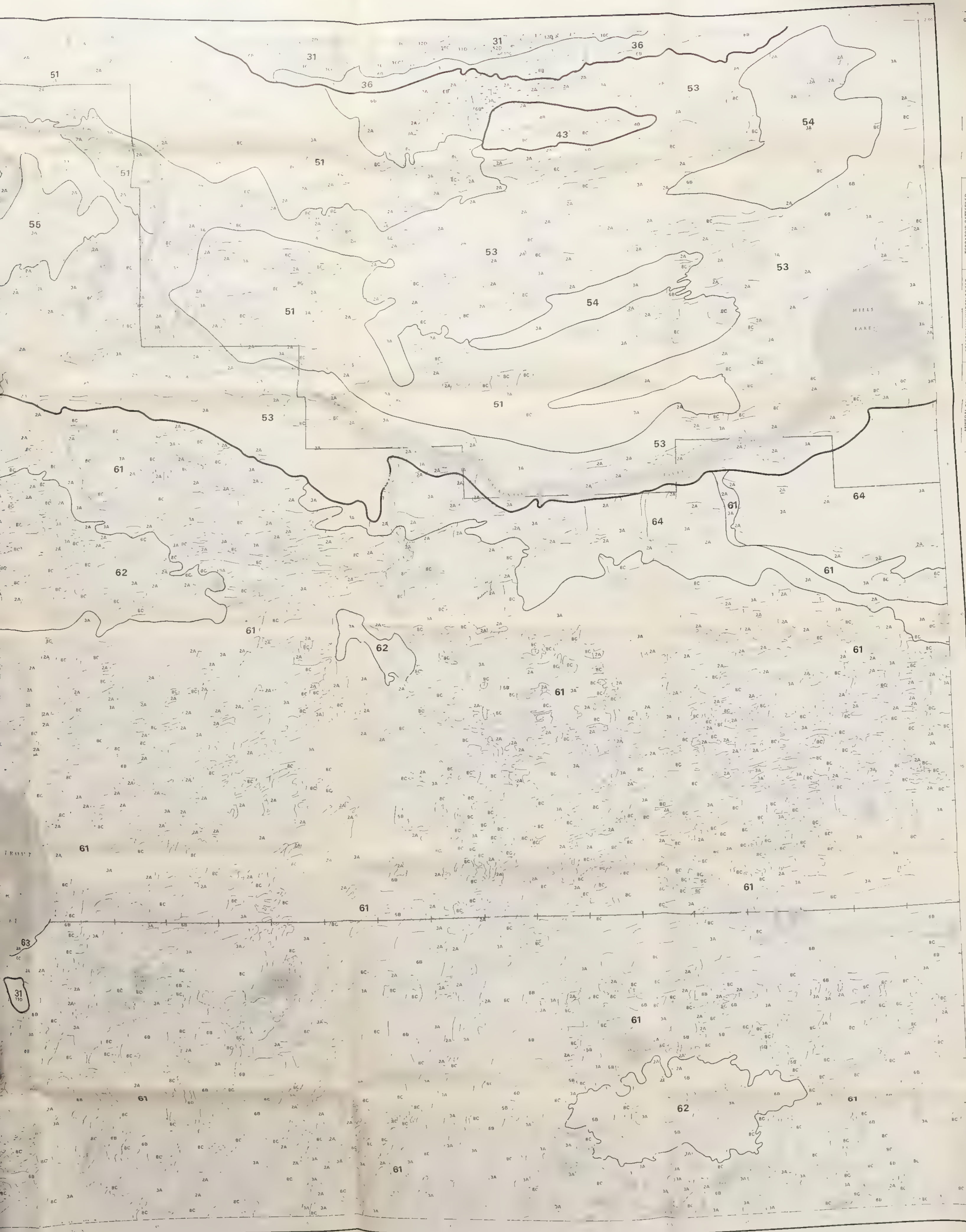
(based on landscape surveys in the southern and central Mackenzie River valley during 1971 and 1972 using air-photo interpretation, supplemented by ground observations)

Mountain outcrops and screes	Least susceptible	Moderately susceptible	Strongly susceptible	Most susceptible
not differentiated	Steeply sloping to flat lands, with the summer permafrost table at about 60" depth or greater; locally ice lenses nearer the surface. Not especially susceptible to damage, except where ice lenses are near the land surface when thermal subsidence may occur. Grassy flora often pioneers damaged areas	Steeply sloping to flat lands, with the summer permafrost table at about 30"-60" depth locally irregularly distributed, susceptible to damage where the permafrost table or ice lenses occurring locally near the land surface allow the possibility of thermal subsidence, and where slopes, for example those dropping to rivers, allow gully erosion. *Sphagnum* mosses often pioneer damaged areas.	Mostly flat lands, except for peripheral bluffs, with the summer permafrost table at about 10"-30" depth, more widespread where textures are silty. After the vegetative and organic cover is pierced by a damaging agent, the permafrost table lowers from about 20"-36", naturally-occurring depressions enlarge through thermal subsidence, and gullying erosion may occur on peripheral bluffs. Sedges and willows often pioneer damaged areas	Sloping lands with the summer permafrost table at about 10"-30" depth. After the vegetative and organic cover is pierced by a damaging agent, the permafrost table lowers from about 10"-36", and gullying erosion can be severe and widespread, usually leaving bare ground. Once the thermal insulation given by the vegetative and organic cover is removed from a sufficiently large area, the erosional process can be self-perpetuating, until the slopes become stable enough for revegetation to commence.

(Before averaging, all depths measured to the permafrost table were adjusted to the mid-August value)

All major river banks in Land Regions 5-1 are susceptible to damage. Corrosion repeatedly exposes mineral soil and any frozen ground present, resulting in slumping, to a degree partly dependent on the sedimentary layering





LANDSCAPE SURVEY AND TERRAIN SUSCEPTIBILITY TO DAMAGE FOR THE SOUTHERN AND CENTRAL MACKENZIE RIVER VALLEY

WITH SPECIAL REFERENCE TO THE DEPTH OF THE ACTIVE LAYER, SLOPE AND TEXTURE

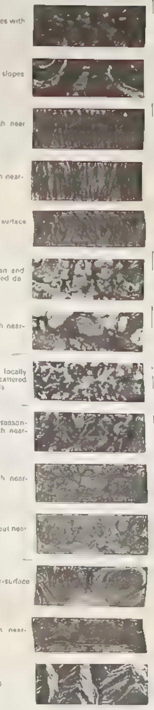
Scale 1:250,000 Echelle

Landscape Survey by C. B. Crampton. Maps compiled by C. B. Crampton and M. R. Ross, Canadian Forestry Service, Department of the Environment, for the Environmental—Social Program, Northern Pipelines, Task Force on Northern Oil Development, Government of Canada.

Soil Research Institute, Research Branch, Canada Depart-
1973

*GROUPING OF SIMILAR LANDSCAPE UNITS

GROUP	LAND SYSTEM NO	GENERAL CHARACTER
LINEAR PATTERNED SLOPES	14	Hilly moraine and finely lineated slopes with near surface permafrost
	13	Rocky plateaus, and finely lineated slopes with near-surface permafrost.
	12	Gentle coarsely lineated slopes with near surface permafrost
	11	Moderate, finely lineated slopes with near-surface permafrost
	6	Steep lineated slopes without near surface permafrost
TERRAZOID PATTERNED PEATY LANDS	10	Hummocky peat plateaus with lichen and near surface permafrost, and scattered depressions containing summer pools
	9	Hummocky peaty mineral soils with near-surface permafrost
	8	Peat plateaus with labrador tea, locally with near-surface permafrost, and scattered depressions containing summer pools
SEASONALLY WATERLOGGED LANDS	5	Drumlinoid terrain and intervening seasonally waterlogged lands, locally with near-surface permafrost
	4	Seasonally waterlogged lands with near-surface permafrost
	3	Seasonally waterlogged lands without near surface permafrost
MINERAL SOILS AND ROCK OUTCROPS	7	Freer-drained mineral soils with near-surface permafrost
	2	Freer-drained mineral soils without near-surface permafrost
	1	Mountain rock outcrops and screes



Stereograms in text, photo miniatures for quick correlation

LEGEND

The first digit of each full unit symbol gives the Land Region or climatic zone; the second digit the Land District or surficial geology, and these are shown on the map in large numerals. The small numeral indicates the Land System or landscape unit; in most cases this information is shown separately on the map.

Land region — 43 — Land district

Land system

description of each unit is given in the ... typical ground vegetation
The legend gives the general tree height of ... systems

LANDSCAPE

The landscape survey is based on air-photo interpretation checked by ground observations. Patterns of landforms (drainage) plus vegetation have been delineated that can be identified on air photographs and are indicative of permafrost characteristics. These patterns can be used in mapping lands outside the original area by air-photo interpretation alone, which increases the value of the survey and provides a basis for possible extension of the area of interest.

LAND REGIONS

Land Regions are equivalent to climatic zones in several ways. They are characterized by soil types on the sites with freer drainage (terrace and river banks, morainal and glaciofluvial ridges) that range from podzolized soils in the southernmost part, Land Region 6, to cryoturbated soils in the northernmost, highest area, Land Region 1. Also, the regions differ in the proportions of seasonally frozen and unfrozen land. Hence, land susceptible to damage from careless traffic becomes progressively more widespread from south to north; lineated slopes are the most easily harmed.

LAND DISTRICTS

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CORRELATION

A count based on the standard Mercator grid was used for correlation with vegetation maps produced by W. L. Wallace (Canadian Forestry Service). This correlation provided information on general tree heights, and confirmed observations on associations of general ground vegetation and landscape units (Land System). Correlations with R. M. Strang's investigations of disturbed sites revealed the vegetation normally established on each landscape unit after disturbance.

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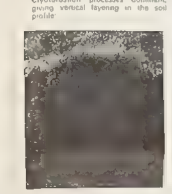
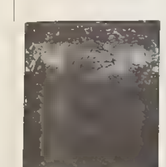
LAND REGIONS (1st digit)
(climatic zones)

Characterized by the soils on the most constantly similar sites from Region to Region, the freer-drained mineral soil sites. The profound climatic change from the tundra Mackenzie Mountain Land Region in the NW, to the boreal Trout Lake Land Region in the S. is best illustrated by:

Cryoturbation processes dominant, giving vertical layering in the soil profile



Pedological processes dominant, giving horizontal layering in the soil profile



LAND DISTRICTS (2nd digit)
(dominant parent material)

1 silty clayey morainal
2 sandy-gravelly morainal
3 silty clayey lacustrine
4 sandy clayey lacustrine
5 eolian
6 shallow bedrock

LAND SYSTEMS (3rd digit)
*(landscape unit composite of landform, drainage and vegetation)

mostly white spruce, up to 75 ft. high — mostly white spruce up to 50 ft. high — mostly scattered black spruce up to 25 ft. high — widely scattered black spruce up to 15 ft. high

rock flora — herbaceous-grassy — sedgy-sphagnaceous — sphagnaceous-lichenous — (sphagnaceous in surficial runnels, but otherwise increasingly lichenous)

Land Region	Land Districts	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 MACKENZIE MOUNTAIN, Turbic regosol	16	16 1						16 7						16 13	
2 CARCAJOU CANYON, Cryic regosol	21	21 1			21 4	21 5	21 6	21 7		21 9	21 10	21 11	21 12	21 13	21 14
	22					22 5				22 9					
	24	24 1				24 5		24 7		24 9	24 10			24 13	
	26	26 1				26 5		26 7		26 9	26 10	26 11	26 12	26 13	26 14
3 HORN PLATEAU, Alpine eutric brunisol	31	31 1	31 2		31 4	31 5	31 6		31 8	31 9	31 10	31 11	31 12	31 13	
	32		32 2			32 5						32 11			
	33		33 2		33 4				33 8	33 9	33 10		33 12		
	36	36 1	36 2		36 4	36 5	36 6		36 8	36 9	36 10	36 11	36 12	36 13	
4 NORMAN WELLS, Degraded eutric brunisol	41	41 1	41 2		41 4	41 5	41 6		41 8	41 9	41 10	41 11	41 12		
	42					42 5									
	43	43 1	43 2		43 4	43 5	43 6		43 8	43 9					
	44		44 2		44 4										
	45		45 2		45 4				45 8						
5 FORT SIMPSON, Degraded dystric brunisol	51	51 1	51 2	51 3		51 5	51 6		51 8						
	52			52 3		52 5			52 8						
	53		53 2	53 3			53 6		53 8						
	54		54 2	54 3			54 6								
	55			55 3											
	56	56 1	56 2	56 3			56 6		56 8						
6 TROUT LAKE, Podzolized dystric brunisol	61	61 1	61 2	61 3		61 5	61 6		61 8						
	62		62 2	62 3		62 5	62 6		62 8						
	63			63 3			63 6								
	64		64 2	64 3					64 8						

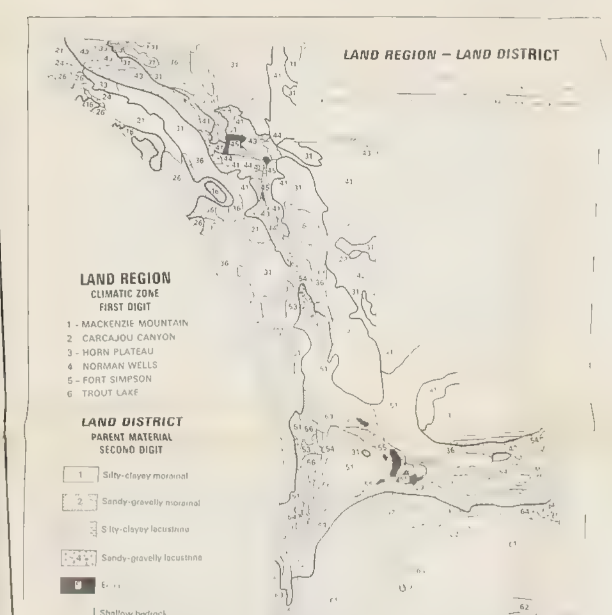
*For identification of Land Systems see "Grouping of similar Landscape Units"

LEGEND FOR LANDSCAPE SURVEY AND DAMAGE SUSCEPTIBILITY MAP

(based on landscape surveys in the southern and central Mackenzie River valley during 1971 and 1972, using air-photo interpretation supplemented by ground observations)

not differentiated	A	B	C	D
Mountain outcrops and screes	**Least susceptible** Steeply sloping to flat lands, with the summer permafrost table at about 60" depth or greater locally ice lenses nearer the surface. Not especially susceptible to damage except where ice lenses are near the land surface when thermal subsidence may occur. Grassy flora often pioneers damaged areas	**Moderately susceptible** Steeply sloping to flat lands, with the summer permafrost table at about 30"-60" depth locally irregularly distributed, susceptible to damage where the permafrost table or ice lenses occurring locally near the land surface allow the possibility of thermal subsidence, and where slopes, for example those dropping to rivers, allow gully erosion. Sphagnum mosses often pioneer damaged areas	**Strongly susceptible** Mostly flat lands, except for peripheral bluffs, with the summer permafrost table at about 10"-30" depth, more widespread where textures are silty. After the vegetative and organic cover is pierced by a damaging agent, the permafrost table lowers from about 20"-36", naturally occurring depressions enlarge through thermal subsidence and gullying erosion may occur on peripheral bluffs. Sedges and willows often pioneer damaged areas	**Most susceptible** Sloping lands with the summer permafrost table at about 10"-30" depth. After the vegetative and organic cover is pierced by a damaging agent, the permafrost table lowers from about 10"-36" and gullying erosion can be severe and widespread, usually leaving bare ground. Once the thermal insulation given by the vegetative and organic cover is removed from a sufficiently large area, the erosional process can be self-perpetuating until the slopes become stable enough for revegetation to commence

Before averaging, all depths reduced to the permafrost table were adjusted to the mid-August values




LEGEND
LAND REGION – LAND DISTRICT
LAND REGION
CLIMATIC ZONE
FIRST DIGIT
1 – MACKENZIE MOUNTAIN
2 – CARCAJOU CANYON
3 – HORN PLATEAU
4 – NORMAN WELLS
5 – FORT SIMPSON
6 – TROUT LAKE
LAND DISTRICT
PARENT MATERIAL
SECOND DIGIT
Silty-clayey morainal
Sandy-gravelly morainal
Silty-clayey lacustrine
Sandy-gravelly lacustrine
Shallow bedrock
Land region
Land district
Land system
LAND REGIONS (1st digit)
Characterized by the soils on the most constantly similar sites from Region to Region, the freer-drained mineral soil sites. The profound climatic change from the tundra Mackenzie Mountain Land Region in the NW, to the boreal Trout Lake Land Region in the S is best illustrated by
Cryoturbation processes dominant, giving vertical layering in the soil profile.
1 MACKENZIE MOUNTAIN "Turbic regosol
2 CARCAJOU CANYON Cryic regosol
3 HORN PLATEAU Alpine eutric brunisol
4 NORMAN WELLS Degraded eutric brunisol
5 FORT SIMPSON Degraded dystric brunisol
6 TROUT LAKE "Podzolized" dystric brunisol
Pedological processes dominant, giving horizontal layering in the soil profile
LAND DISTRICTS (2nd digit)
1 silty clayey morainal
2 sandy-gravelly morainal
3 silty-clayey lacustrine
4 sandy-clayey lacustrine
5 eolian
6 shallow bedrock
LAND SYSTEMS (3rd digit)
mostly white spruce up to 75 ft. high
mostly white spruce up to 50 ft. high
mostly scattered black spruce up to 25 ft. high
widely scattered black spruce up to 15 ft. high
rock flora
herbaceous-grassy
sedgy-sphagnaceous
sphagnaceous-lichenous
(sphagnaceous in surficial runnels, but otherwise increasingly lichenous)
increasing latitude, elevation or distance from large water bodies
*For identification of Land Systems, see "Grouping of similar Landscape Units"
LEGEND FOR LANDSCAPE
SURVEY AND DAMAGE
SUSCEPTIBILITY MAP
(based on landscape surveys in the southern and central Mackenzie River valley during 1971 and 1972 using air photo interpretation supplemented by ground observations)
Mountain outcrops and screes
Least susceptible
Steeply sloping to flat lands, with the summer permafrost table at about 60" depth or greater locally ice lenses nearer the surface. Not especially susceptible to damage except where ice lenses are near the land surface when thermal subsidence may occur. Grassy flora often pioneers damaged areas.
Moderately susceptible
Steeply sloping to flat lands, with the summer permafrost table at about 30"-60" depth locally irregularly distributed susceptible to damage where the permafrost table or ice lenses occurring locally near the land surface allow the possibility of thermal subsidence, and where slopes, for example those dropping to rivers, allow gully erosion. Sphagnum mosses often pioneer damaged areas.
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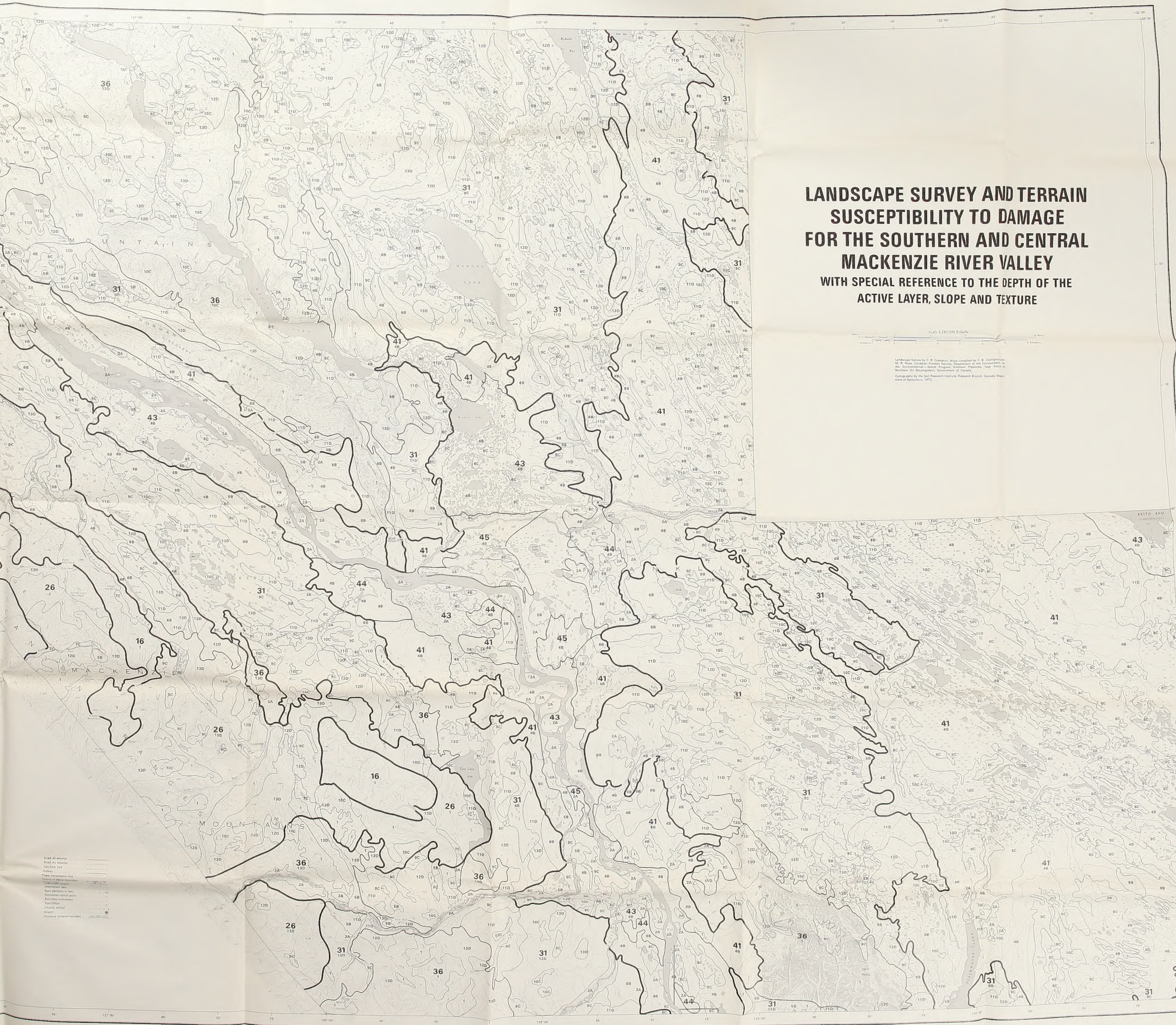
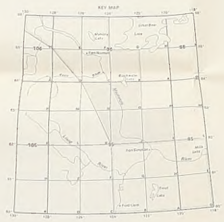
Mostly flat lands except for peripheral bluffs with the summer permafrost table at about 10"-30" depth, more widespread where textures are silty. After the vegetative and organic cover is pierced by a damaging agent, the permafrost table lowers from about 20"-36" naturally occurring depressions enlarge through thermal subsidence and gullying erosion may occur on peripheral bluffs. Sedges and willows often pioneer damaged areas.
Most susceptible
Sloping lands with the summer permafrost table at about 10"-30" depth. After the vegetative and organic cover is pierced by a damaging agent, the permafrost table lowers from about 10"-36" and gullying erosion can be severe and widespread, usually leaving bare ground. Once the thermal insulation given by the vegetative and organic cover is removed from a sufficiently large area the erosional process can be self perpetuating, until the slopes become stable enough for revegetation to commence.
not differentiated
A
B
C
D
(Before averaging, all depths measured to the permafrost table were adjusted to the mid August value)
*GROUPING OF SIMILAR LANDSCAPE UNITS
GROUP
LAND SYSTEM NO
GENERAL CHARACTER
LINEAR PATTERNED SLOPES
14 Hilly moraine and finely lineated slopes with near-surface permafrost
13 Rocky plateaus, and finely lineated slopes with near-surface permafrost.
12 Gentle, coarsely lineated slopes with near-surface permafrost
11 Moderate, finely lineated slopes with near-surface permafrost
6 Steep lineated slopes without near-surface permafrost
TERRAZOID-PATTERNED PEATY LANDS
10 Hummocky peat plateaus with lichen and near-surface permafrost, and scattered depressions containing summer pools
9 Hummocky peaty mineral soils with near-surface permafrost
8 Peat plateaus with labrador tea, locally with near-surface permafrost and scattered depressions containing summer pools
SEASONALLY WATERLOGGED LANDS
5 Drumlinoid terrain and intervening seasonally waterlogged lands, locally with near-surface permafrost
4 Seasonally waterlogged lands with near-surface permafrost
3 Seasonally waterlogged lands without near-surface permafrost
MINERAL SOILS AND ROCK OUTCROPS
7 Freer drained mineral soils with near-surface permafrost
2 Freer-drained mineral soils without near surface permafrost
1 Mountain rock outcrops and screes
Stereograms in text; photo-miniatures for quick correlation
FRANKLIN MOUNTAINS
MACKENZIE MOUNTAINS
MACKENZIE


LANDSCAPE SURVEY AND TERRAIN SUSCEPTIBILITY TO DAMAGE FOR THE SOUTHERN AND CENTRAL MACKENZIE RIVER VALLEY
WITH SPECIAL REFERENCE TO THE DEPTH OF THE ACTIVE LAYER, SLOPE AND TEXTURE
Scale 1:250,000 Echelle
Landscape Survey by C. B. Crampton, Maps compiled by C. B. Crampton and M. R. Ross, Canadian Forestry Service, Department of the Environment, for the Environmental—Social Program, Northern Pipelines, Task Force on Northern Oil Development, Government of Canada.
Cartography by the Soil Research Institute, Research Branch, Canada Department of Agriculture, 1973.
MOUNTAINS
MACKENZIE
MOUNTAINS

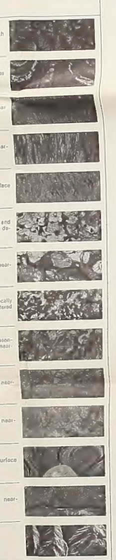
SHEET NO. 4



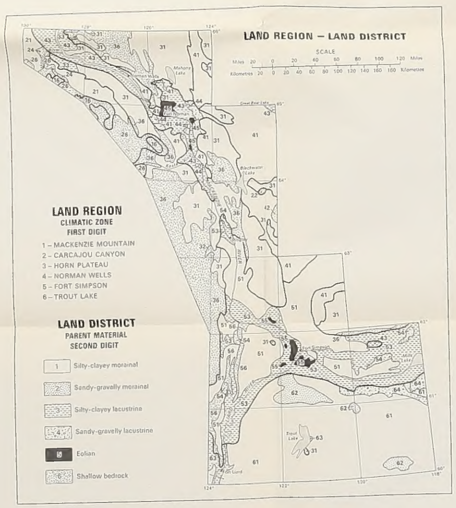
Land region
Land district
Land system

*GROUPING OF SIMILAR LANDSCAPE UNITS

GROUP	LAND SYSTEM NO.	GENERAL CHARACTER
LINEAR-PATTERNED SLOPES	14	Hilly moraine and finely lineated slopes with near-surface permafrost.
	13	Rocky plateaus, and finely lineated slopes with near-surface permafrost.
	12	Gentle, coarsely lineated slopes with near-surface permafrost.
	11	Moderate, finely lineated slopes with near-surface permafrost.
	6	Steep, lineated slopes without near-surface permafrost.
TERRAZOID-PATTERNED PEATY LANDS	10	Hummocky peat plateaus with lichen and near-surface permafrost, and scattered depressions containing summer pools.
	9	Hummocky, peaty mineral soils with near-surface permafrost.
	8	Peat plateaus with labrador tea, locally with near-surface permafrost, and scattered depressions containing summer pools.
SEASONALLY WATERLOGGED LANDS	5	Drumlinoid terrain and intervening seasonally waterlogged lands, locally with near-surface permafrost.
	4	Seasonally waterlogged lands with near-surface permafrost.
	3	Seasonally waterlogged lands without near-surface permafrost.
MINERAL SOILS AND ROCK OUTCROPS	7	Freer-drained mineral soils with near-surface permafrost.
	2	Freer-drained mineral soils without near-surface permafrost.
	1	Mountain rock outcrops and screes.



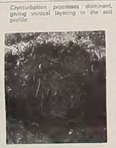
Stereograms in text; photo-miniatures for quick contrast.



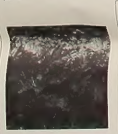
LAND REGIONS (1st digit)
(climatic zones)

Characterized by the soils on the most constantly similar sites from Region to Region, the freer-drained mineral soil sites. The profound climatic change from the tundra Mackenzie Mountain Land Region in the NW, to the boreal Trout Lake Land Region in the S. is best illustrated by:

Cryoturbation processes dominant, giving vertical layering in the soil profile:



Pedological processes dominant, giving horizontal layering in the soil profile.



LAND DISTRICTS (2nd digit)
(dominant parent material)

1. silty-clayey morainal
2. sandy-gravelly morainal
3. silty-clayey lacustrine
4. sandy-clayey lacustrine
5. eolian
6. shallow bedrock

LAND SYSTEMS (3rd digit)
*landscape unit: composite of landform, drainage and vegetation

rock flora — mostly white spruce, up to 75 ft. high, herbaceous-grassy — mostly white spruce, up to 50 ft. high, sedgy-sphagneous — mostly scattered black spruce up to 25 ft. high, sphagneous-lichenous — widely scattered black spruce up to 15 ft. high (sphagneous in surficial runnels, but otherwise increasingly lichenous)

LAND REGIONS	LAND DISTRICTS	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 MACKENZIE MOUNTAIN "Turbic" regosol	16	16 1						16 7					16 12		
2 CARCAJOU CANYON Cryic regosol	21 22 24 26	21 1 24 1 26 1			21 4	21 5 22 5 24 5 26 5	21 6	21 7 24 7 26 7		21 9 22 9 24 9 26 9	21 10 24 10 26 10	21 11 26 11	21 12 26 12	21 13 24 13 26 13	21 14 26 14
3 HORN PLATEAU Alpine eutric brunisol	31 32 33 36	31 1 36 1	31 2 32 2 33 2 36 2		31 4 33 4 36 4	31 5 32 5 36 5	31 6 36 6		31 8 33 8 36 8	31 9 33 9 36 9	31 10 33 10 36 10	31 11 32 11 36 11	31 12 33 12 36 12	31 13 36 13	
4 NORMAN WELLS Degraded eutric brunisol	41 42 43 44 45	41 1 43 1	41 2 43 2 44 2 45 2		41 4 43 4 44 4 45 4	41 5 42 5 43 5	41 6 43 6		41 8 43 8 45 8	41 9 43 9	41 10	41 11	41 12		
5 FORT SIMPSON Degraded dystric brunisol	51 52 53 54 55 56	51 1 56 1	51 2 53 2 54 2 56 2	51 3 52 3 53 3 54 3 55 3 56 3		51 5 52 5	51 6 53 6 54 6 56 6		51 8 52 8 53 8 56 8						
6 TROUT LAKE "Podzolized" dystric brunisol	61 62 63 64	61 1	61 2 62 2 64 2	61 3 62 3 63 3 64 3		61 5 62 5	61 6 62 6 63 6		61 8 62 8 64 8						

Increasing latitude, elevation or distance from large water bodies

*For identification of Land Systems, see "Grouping of similar Landscape Units"

LEGEND FOR SURVEY AND DAMAGE SUSCEPTIBILITY MAP

(based on landscape surveys in the southern and central Mackenzie River valley during 1971 and 1972, using air-photo interpretation, supplemented by ground observations)

	Least susceptible	Moderately susceptible	Strongly susceptible	Most susceptible
Mountain outcrops and screes	Steeply sloping to flat lands, with the summer depth of thaw, mostly ice lenses nearer the surface. Not especially susceptible to damage, except where ice lenses are near the land surface when thermal subsidence may occur. Grassy flora often pioneers damaged areas.	Steeply sloping to flat lands, with the summer permafrost table at about ... gularly distributed, susceptible to damage where the permafrost table or ice lenses occurring locally near the land surface allow the possibility of thermal subsidence, and where slopes, for example those dropping to rivers, allow gully erosion. *Sphagnum* mosses often pioneer damaged areas.	Mostly flat lands, except for peripheral bluffs, with the summer permafrost table at about 10"-30" depth ... After the vegetative and organic cover is pierced by a damaging agent, the permafrost table lowers from about 20"-36", naturally-occurring depressions enlarge through thermal subsidence, and gullying erosion may occur on peripheral bluffs. Sedges and willows often pioneer damaged areas.	Sloping lands with the summer permafrost table at about 10"-30" depth. After the vegetative and organic cover is pierced by a damaging agent, the permafrost table lowers from about 10"-36", and gullying erosion can be severe and widespread, usually leaving bare ground. Once the thermal insulation given by the vegetative and organic cover is removed from a sufficiently large area, the erosional process can be self-perpetuating, until the slopes become stable enough for revegetation to commence.
not differentiated	A	B	C	D

(Before averaging, all depths measured to the permafrost table were adjusted to the mid-August value)

All major river banks in Land Regions 6-1 are susceptible to damage. Corrasion repeatedly exposes mineral soil and any frozen ground present, resulting in slumping, to a degree partly dependent on the sedimentary layering.

LEGEND

The first digit of each full unit symbol gives the Land Region or climatic zone; the second digit the Land District or surficial geology; and these are shown on the map in large numerals. The small numeral indicates the Land System or landscape unit. In most cases this information is shown separately on the map.

Land region — 43 — Land district
Land system

All major areas have been identified in terms of the dominant landscape unit number. The order of landscape units in the legend (1-14) is generally that of susceptibility to damage, though local conditions can change the relative position. Hence, the landscape units have been assigned to four groups for susceptibility to damage from careless traffic. A broad regional appraisal can be made by viewing only the distribution of these four groups. A more detailed assessment can be made by examining the distribution of individual landscape units, and for this purpose a brief description of each unit is given in the table below the legend. The legend gives the general tree height and typical ground vegetation associated with the different land systems.

LANDSCAPE

The landscape survey is based on air-photo interpretation, checked by ground observations. Patterns of landforms (drainage) plus vegetation have been delineated that can be identified on air photographs and are indicative of permafrost characteristics. These patterns can be used in mapping lands outside the original area by air-photo interpretation alone, which increases the value of the survey and provides a basis for possible extension of the area of interest.

LAND REGIONS

Land Regions are equivalent to climatic zones in several ways. They are characterized by soil types on the sites with freer drainage (terrace and river banks, morainal and glaciofluvial ridges) that range from podzolized soils in the southernmost part, Land Region 6, to cryoturbated soils in the northernmost, highest area, Land Region 1. Also, the regions differ in the proportions of seasonally frozen and unfrozen land. Hence, land susceptible to damage from careless traffic becomes progressively more widespread from south to north; lineated slopes are the most easily harmed.

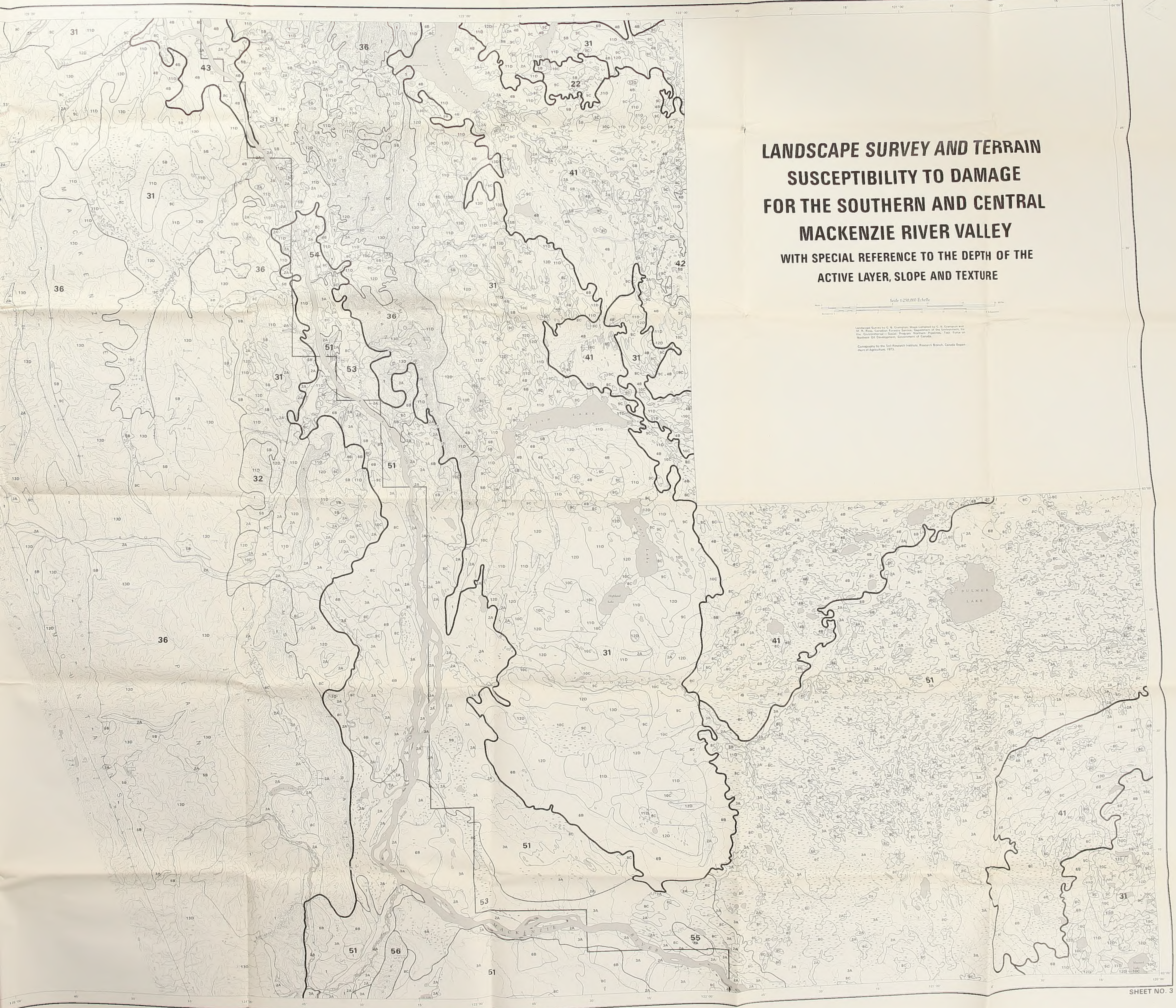
LAND DISTRICTS

Land Districts are based on surface geology maps produced by D. L. Hughes, R. J. Fulton, N. W. Rutter, and P. T. Hanley (Geological Survey of Canada). Predominantly silty and clayey deposits of morainal and lacustrine material have been delineated separately from sandy and gravelly deposits. Silty and clayey deposits form the most extensive frozen areas, which are the most susceptible to damage.

CORRELATION

A count based on the standard Mercator grid was used for correlation with vegetation maps produced by W. L. Wallace (Canadian Forestry Service). This correlation provided information on general tree heights, and confirmed observations on associations of general ground vegetation and landscape units (Land System). Correlations with R. M. Strang's investigations of disturbed sites revealed the vegetation normally established on each landscape unit after disturbance.

The data for this report was obtained from investigations carried out under the Environmental—Social Program, Northern Pipelines, of the Task Force on Northern Oil Development, Government of Canada.



LANDSCAPE SURVEY AND TERRAIN
SUSCEPTIBILITY TO DAMAGE
FOR THE SOUTHERN AND CENTRAL
MACKENZIE RIVER VALLEY
WITH SPECIAL REFERENCE TO THE DEPTH OF THE
ACTIVE LAYER, SLOPE AND TEXTURE
Scale 1:250,000 Echelle
Landscape Survey by C. B. Crampton. Maps compiled by C. B. Crampton and M. R. Ross, Canadian Forestry Service, Department of the Environment, for the Environmental—Social Program Northern Pipelines, Task Force on Northern Oil Development, Government of Canada.
Cartography by the Soil Research Institute, Research Branch, Canada Department of Agriculture, 1973.
MACKENZIE
BULMER LAKE
MACKENZIE RIVER
SHEET NO. 3